DEPARTMENT OF COMMERCE AND LABOR
US COAST AND GEODETIC SURVEY
O. H. TITTMANN
SUPERINTENDENT

GEODESY

# EFFECT OF TOPOGRAPHY AND ISOSTATIC COMPENSATION UPON THE INTENSITY OF GRAVITY

## (SECOND PAPER)

BY

WILLIAM BOWIE
Inspector of Geodetic Work and Chief of the Computing Division
Coast and Geodetic Survey

SPECIAL PUBLICATION No. 12

WASHINGTON
GOVERNMENT PRINTING OFFICE
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# CONTENTS.

# ILLUSTRATIONS.

# EFFECT OF TOPOGRAPHY AND ISOSTATIC COMPENSATION UPON THE INTENSITY OF GRAVITY.

## SECOND PAPER.

By William Bowie,
*Inspector of Geodetic Work and Chief of the Computing Division, Coast and Geodetic Survey.*

### GENERAL STATEMENT.

In September, 1909, Mr. J. F. Hayford, then inspector of geodetic work, presented a paper to the International Geodetic Association at London which gave a preliminary report on the investigation made by him on the effect of topography and isostatic compensation upon the intensity of gravity. That report has appeared as pages 365–389 of volume 1 of the Report of the Sixteenth General Conference of the International Geodetic Association in 1909. Fifty-six gravity stations in the United States were used in that report.

Before the final report of his investigation could be completed additional gravity stations were established in the United States by authority of the Superintendent, under the direction of the writer, as inspector of geodetic work, and in order that all available data might be used for the basis of the complete report 33 additional stations were added to the 56 stations, making 89 in all. In the final report on the new method of reducing gravity observations Messrs. Hayford and Bowie worked together and appeared as coauthors. That report bears the title The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, Special Publication No. 10 of the Coast and Geodetic Survey, 1912.

Still more gravity stations in the United States are now available, making 124 stations in all, and it has been decided that a supplementary investigation of the effect of topography and isostatic compensation upon the intensity of gravity should be made. This present paper is a report on the second investigation. These reports on the investigations of the effect of topography and isostatic compensation upon the intensity of gravity are very closely allied to and may be considered as supplementary to the two publications of the United States Coast and Geodetic Survey by Hayford, entitled The Figure of the Earth and Isostasy from Measurements in the United States, and A Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy. In these two publications only deflections of the vertical were utilized.

The writer wishes to express his appreciation of the valuable assistance rendered by those members of the computing division of the United States Coast and Geodetic Survey who were connected with this investigation, especially Miss S. Beall and Mr. C. H. Swick.

Anyone wishing to have full information on the subjects treated here should use with this paper the report of the first investigation entitled Effect of Topography and Isostatic Compensation upon the Intensity of Gravity. In that publication are given the detailed description of the new methods of reducing the gravity stations, together with the reduction tables for obtaining the topographic correction and the correction for isostatic compensation, and the formulas by which the values in the tables were computed.

## ISOSTASY DEFINED.

It is desirable that the reader who is not already thoroughly familiar with the contents of Effect of Topography and Isostatic Compensation upon the Intensity of Gravity be given concise definitions of the terms and phrases used, and for that purpose portions of pages 6 and 7 of that publication are repeated here.

If the earth were composed of homogeneous material, its figure of equilibrium, under the influence of gravitation [1] and its own rotation, would be an ellipsoid of revolution.

The earth is composed of heterogeneous material which varies considerably in density. If this heterogeneous material were so arranged that its density at any point depended simply upon the depth of that point below the surface, or, more accurately, if all the material lying at each equipotential surface (rotation considered) were of one density, a state of equilibrium would exist, and there would be no tendency toward a rearrangement of masses. The figure of the earth in this case would be a very close approximation to an ellipsoid of revolution.

If the heterogeneous material composing the earth were not arranged in this manner at the outset, the stresses produced by gravity would tend to bring about such an arrangement; but as the material is not a perfect fluid, since it possesses considerable viscosity, at least near the surface, the rearrangement will be imperfect. In the partial rearrangement some stresses will still remain, different portions of the same horizontal stratum may have somewhat different densities, and the actual surface of the earth will be a slight departure from the ellipsoid of revolution in the sense that above each region of deficient density there will be a bulge or bump on the ellipsoid, and above each region of excessive density there will be a hollow, relatively speaking. The bumps on this supposed earth will be the mountains, the plateaus, the continents, and the hollows will be the oceans. The excess of material represented by that portion of the continent which is above sea level will be compensated for by a defect of density in the underlying material. The continents will be floated, so to speak, because they are composed of relatively light material; and, similarly, the floor of the ocean will, on this supposed earth, be depressed because it is composed of unusually dense material. This particular condition of approximate equilibrium has been given the name "isostasy."

The adjustment of the material toward this condition, which is produced in nature by the stresses due to gravity, may be called the "isostatic adjustment."

The compensation of the excess of matter at the surface (continents) by the defect of density below, and of surface defect of matter (oceans) by excess of density below, may be called the "isostatic compensation."

Let the depth below sea level within which the isostatic compensation is complete be called the "depth of compensation." At and below this depth the condition as to stress of any element of mass is isostatic; that is, any element of mass is subject to equal pressures from all directions as if it were a portion of a perfect fluid. Above this depth, on the other hand, each element of mass is subject in general to different pressures in different directions—to stresses which tend to distort it and to move it.

Consider the relations of the masses, densities, and volumes, above the depth of compensation, fixed by the preceding definition. The mass in any prismatic column which has for its base a unit area of the horizontal surface which lies at the depth of compensation, for its edges vertical lines (lines of gravity) and for its upper limit the actual irregular surface of the earth (or the sea surface, if the area in question is beneath the ocean), is the same as the mass in any other similar prismatic column having any other unit area of the same surface for its base.

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[1] In this publication "gravity" is the term used for the phenomenon of weight or of the acceleration of a body falling to the earth, and, at any place, it is the resultant of the earth's attractive force, "gravitation," and the centrifugal force due to the earth's rotation. This distinction between the terms "gravity" and "gravitation" is not always clearly drawn.

In general it will be found that throughout this publication the attraction (expressed in dynes) is dealt with directly by preference rather than its numerical equivalent, the acceleration (expressed in centimeters and seconds). This preference is due to the belief that thereby circumlocutions are avoided and greater clearness secured in the conceptions.

The most unusual feature of the first investigation of the effect of topography and isostatic compensation upon the intensity of gravity is that all of the topography[1] of the world and its isostatic compensation are taken into consideration in computing the effect on gravity at a station.

For the purpose of making the computations the earth's crust is assumed to be in a state of perfect isostasy, with each topographic feature compensated for by a deficiency (or excess) of mass directly under it; and it is assumed that this compensating deficiency (or excess) of mass is uniformly distributed to a depth of 113.7 kilometers. This depth is that resulting from the investigation of The Figure of the Earth and Isostasy from Measurements in the United States. This value has been used in the investigations of gravity and in the new method of reduction, including the computations of the reduction tables. The better value for the depth of compensation of 122.2 kilometers resulting from the Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy was not available at the time the gravity investigations were begun. This slight difference between the adopted and the better value of the depth of compensation does not affect the anomalies materially, nor would a change to the other depth have varied in the slightest degree any of the conclusions drawn from the gravity investigations.

The mean density of the solid portion of the earth's surface is assumed to be 2.67, and the density of the ocean water is assumed to be 1.027.

Agreeing with similar statements made in the two publications on the figure of the earth and isostasy and in the one on the investigation of gravity, the writer does not believe that any one of the assumptions stated above is exactly true.

The average density, 2.67, is no doubt somewhat in error, and it is reasonably certain that there are many areas where the average densities of the surface materials are very different from this adopted mean density. The mean depth of compensation is probably not exactly 113.7 kilometers, and at different portions of the earth's crust the depth of compensation may be very much greater or less than 113.7 kilometers. It is probable that the deficiency (or excess) of mass under a topographic feature is not distributed with exact uniformity with respect to depth, and it is also probable that the isostatic compensation or deficiency (or excess) of mass is not located exactly under a topographic feature. It is believed, however, that the assumptions made in connection with the investigations are very close to the truth. The anomalies or differences between the observed gravity and the value computed by the new method give an idea of the inaccuracy of the assumptions made. It will be shown later that the anomalies result partly from errors in making the observations and computations, but mostly from an actual departure from the postulated conditions in the earth's crust. After allowing for the errors of observations and computations the remaining anomalies are of such a size that they clearly indicate departures from the condition of perfect isostasy in the earth's crust in the vicinity of the station.

The writer sees no reason for modifying Mr. Hayford's statement which appears on page 169 of The Figure of the Earth and Isostasy from Measurements in the United States, and which is repeated on page 102 of Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, which reads as follows:

> In the above statement that the separate topographic features of the continent are compensated, it is not intended to assert that every minute topographic feature, such, for example, as a hill covering a single square mile, is separately compensated. It is believed that the larger topographic features are compensated. It is an interesting and important problem for future study to determine the maximum size, in the horizontal sense, which a topographic feature may have and still not have beneath it an approximation to complete isostatic compensation. It is certain from the results of this investigation that the continent as a whole is closely compensated and that areas as large as States are also closely compensated. It is the writer's belief that each area as large as one degree square is generally largely compensated. The writer predicts that future investigations will show that the maximum horizontal extent which a topographic feature may have and still escape compensation is between one square mile and one square degree. This prediction is based, in part, upon a consideration of the mechanics of the problem.

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[1] By topography is meant that portion of the earth's crust above sea level and the defect of mass in the oceans.

## PRINCIPAL FACTS FOR 124 STATIONS IN THE UNITED STATES.

There is a statement in Special Publication No. 10, which gives the names of the observers who established the 89 stations considered in that publication. The additional 35 stations used in this report were established as follows: Nos. 102, 103, and 106, by Assistant W. H. Burger in 1909; Nos. 90 to 100, by Assistant H. D. King in 1910 and 1911; and Nos. 101, 103, 104, 105, and 107 to 124 (22 stations in all), by Assistant T. L. Warner in 1911. Station No. 103 was established by Mr. Burger in 1909, but was reoccupied for further observations by Mr. Warner in 1911.

The gravity observations at each of the stations used in this investigations were made with the half-second pendulum apparatus. (See App. 5, Coast and Geodetic Survey Report for 1901, by G. R. Putnam.) The methods used by Mr. Putnam were described by him in Appendix 1, Report for 1894. With only slight modifications these methods were employed by the other observers who used the half-second pendulums. A radical change was made in the method of determining the flexure of the pendulum case. Beginning with the observations in 1909 the flexure was determined in terms of the wave length of light with an interferometer, as described by Mr. W. H. Burger in Appendix 6, Report for 1910.

Complete computations have been made for 124 gravity stations in the United States by the three methods of reduction and the results are shown in the two following tables.

The theoretical value of gravity at sea level was computed by Helmert's formula [1] of 1901 for the Potsdam system, namely,

$$\gamma_0 = 978.030\ (1 + 0.005302 \sin^2 \phi - 0.000007 \sin^2 2\phi).$$

The correction for elevation of station was computed by the formula $-0.0003086\ H$, in which $H$ is the elevation in meters. It should be carefully noted that this is the reduction from sea level to the station, a correction to the theoretical value not to the observed value. This correction takes account of the increased distance of the station from the attracting mass, as if the station were in the air and there were no irregularities in the earth's surface (or topography).

The correction for topography and compensation for the new-method reduction was computed with the reduction tables shown on pages 30–47 of Special Publication No. 10, and the resultant effect was applied as a correction to the theoretical value at sea level.

These corrections are usually applied to the observed values and the results are compared with the theoretical value of gravity at sea level. The method employed in this publication and in Special Publication No. 10 appears to be the more logical one.

The computed value of gravity at the station $g_c$ is the theoretical value of gravity at sea level, $\gamma_0$, corrected for elevation and for topography and compensation. It is therefore directly comparable with $g$, the observed value of gravity at the station. The column $g$–$g_c$ therefore represents the departures of the observed values from computed values based upon the Helmert formula of 1901 upon the usual reduction for elevation, and upon the new-method reductions that take account of topography and compensation.

All observed values, $g$, in the following table depend upon relative determinations with the half-second pendulums and are based on 980.112 dynes (in centimeter-gram-second units) as the absolute value of gravity at the Coast and Geodetic Survey Office at Washington. This value depends upon the absolute determination of the value of gravity at Potsdam,[2] Germany, and upon the relative values of gravity at Potsdam and Washington, as determined by Mr. G. R. Putnam in 1900.[3]

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[1] The Helmert formula for the Vienna system was by mistake used in the computations of gravity at sea level in Coast and Geodetic Survey Special Publication No. 10, The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity. The Vienna formula is identical with that for Potsdam, except that the first term is 978.046. The difference between the two, 0.016, made an error of that amount in each of the anomalies by the two older methods of reduction. It did not, however, make any material changes necessary in the conclusions drawn from the results of the investigation. See footnotes on pp. 12 and 75 of Special Publication No. 10.

[2] Bestimmung der Absoluten Grösze der Schwerkraft zu Potsdam mit Reversionspendeln von Prof. Dr. F. Kühnen und, Prof. Dr. Ph. Furtwängler, Seite 380.

[3] Determination of Relative Value of Gravity in Europe and the United States in 1900, G. R. Putnam, Appendix 5, Coast and Geodetic Survey Report, 1901, pp. 354–355.

The value for Washington was changed from 980.111, the value used in Special Publication No. 10, to 980.112 by a new adjustment of the net of gravity stations. (See pp. 25 and 244 of third volume, by Dr. E. Borrass in 1911, of the Report of the Sixteenth General Conference of the International Geodetic Association at London and Cambridge in 1909.)

*Table of principal facts for 124 gravity stations in the United States.*

| Number and name of station | $\phi$ | $\lambda$ | H | $\gamma_0$ | Correction for elevation | Correction for topography and compensation | Computed gravity at station ($g_c$) | Observed gravity at station ($g$) | $(g-g_c)$ |
|---|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | *Meters.* | | | | | | |
| 1. Key West, Fla. | 24 33.6 | 81 48.4 | 1 | 978.922 | 0.000 | +0.032 | 978.954 | 978.970 | +0.016 |
| 2. West Palm Beach, Fla. | 26 42.8 | 80 02.8 | 2 | 979.073 | − .001 | + .031 | 979.103 | 979.129 | + .026 |
| 3. Punta Gorda, Fla. | 26 56.2 | 82 03 | 1 | 979.089 | .000 | + .020 | 979.109 | 979.127 | + .018 |
| 4. Apalachicola, Fla. | 29 43.5 | 84 58.8 | [illegible] | 979.300 | − .001 | + .015 | 979.314 | 979.322 | + .008 |
| 5. New Orleans, La. | 29 57.0 | 90 04.2 | [illegible] | 979.317 | − .001 | + .013 | 979.329 | 979.324 | − .005 |
| 6. Rayville, La. | 32 28 | 91 45 | 26 | 979.519 | − .008 | + .008 | 979.519 | 979.543 | + .024 |
| 7. Galveston, Tex. | 29 18.2 | 94 47.5 | 3 | 979.267 | − .001 | + .007 | 979.273 | 979.272 | − .001 |
| 8. Point Isabel, Tex. | 26 04.7 | 97 12.4 | 8 | 979.028 | − .002 | + .015 | 979.041 | 979.076 | + .035 |
| 9. Laredo, Tex. | 27 30.5 | 99 31.2 | 129 | 979.131 | − .040 | + .003 | 979.094 | 979.082 | − .012 |
| 10. Austin, Tex. (capitol) | 30 16.5 | 97 44.3 | 170 | 979.343 | − .052 | − .003 | 979.288 | 979.288 | .000 |
| 11. Austin, Tex. (university) | 30 17.2 | 97 44.2 | 189 | 979.344 | − .058 | − .001 | 979.285 | 979.283 | − .002 |
| 12. McAlester, Okla. | 34 56.2 | 95 46.2 | 240 | 979.725 | − .074 | + .001 | 979.652 | 979.633 | − .019 |
| 13. Little Rock, Ark. | 34 45.0 | 92 16.4 | 89 | 979.709 | − .027 | + .001 | 979.683 | 979.721 | + .038 |
| 14. Columbia, Tenn. | 35 36.7 | 87 02.5 | 207 | 979.783 | − .064 | + .006 | 979.725 | 979.759 | + .034 |
| 15. Atlanta, Ga. | 33 45.0 | 84 23.3 | 324 | 979.625 | − .100 | + .014 | 979.539 | 979.524 | − .015 |
| 16. McCormick, S. C. | 33 54.8 | 82 18.0 | 163 | 979.639 | − .050 | + .012 | 979.601 | 979.624 | + .023 |
| 17. Charleston, S. C. | 32 47.2 | 79 56.0 | 6 | 979.545 | − .002 | + .016 | 979.559 | 979.546 | − .013 |
| 18. Beaufort, N. C. | 34 43.1 | 76 39.8 | 1 | 979.706 | .000 | + .036 | 979.742 | 979.729 | − .013 |
| 19. Charlottesville, Va. | 38 02.0 | 78 30.3 | 166 | 979.992 | − .051 | + .002 | 979.943 | 979.938 | − .005 |
| 20. Deer Park, Md. | 39 25.0 | 79 19.8 | 770 | 980.114 | − .238 | + .041 | 979.917 | 979.935 | + .018 |
| 21. Washington, D. C. (Coast and Geodetic Survey Office) | 38 53.2 | 77 00.5 | 14 | 980.067 | − .004 | + .004 | 980.067 | 980.112 | + .045 |
| 22. Washington, D. C. (Smithsonian Institution) | 38 53.3 | 77 01.5 | 10 | 980.067 | − .003 | + .003 | 980.067 | 980.114 | + .047 |
| 23. Baltimore, Md. | 39 17.8 | 76 37.3 | 30 | 980.103 | − .009 | + .006 | 980.100 | 980.097 | − .003 |
| 24. Philadelphia, Pa. | 39 57.1 | 75 11.7 | 16 | 980.162 | − .005 | + .009 | 980.166 | 980.196 | + .030 |
| 25. Princeton, N. J. | 40 21.0 | 74 39.5 | 64 | 980.196 | − .020 | + .013 | 980.189 | 980.178 | − .011 |
| 26. Hoboken, N. J. | 40 44 | 74 02 | 11 | 980.232 | − .003 | + .008 | 980.237 | 980.269 | + .032 |
| 27. New York, N. Y. | 40 48.5 | 73 57.7 | 38 | 980.238 | − .012 | + .011 | 980.237 | 980.267 | + .030 |
| 28. Worcester, Mass. | 42 16.5 | 71 48.5 | 170 | 980.370 | − .052 | + .018 | 980.336 | 980.324 | − .012 |
| 29. Boston, Mass. | 42 21.6 | 71 03.8 | 22 | 980.377 | − .007 | + .013 | 980.383 | 980.396 | + .013 |
| 30. Cambridge, Mass. | 42 22.8 | 71 07.8 | 14 | 980.379 | − .004 | + .010 | 980.385 | 980.398 | + .013 |
| 31. Calais, Me. | 45 11.2 | 67 16.9 | 38 | 980.633 | − .012 | + .010 | 980.631 | 980.631 | .000 |
| 32. Ithaca, N. Y. | 42 27.1 | 76 29.0 | 247 | 980.386 | − .076 | + .005 | 980.315 | 980.300 | − .015 |
| 33. Cleveland, Ohio | 41 30.4 | 81 36.6 | 210 | 980.301 | − .065 | .000 | 980.236 | 980.241 | + .005 |
| 34. Cincinnati, Ohio | 39 08.3 | 84 25.3 | 245 | 980.089 | − .076 | + .002 | 980.015 | 980.004 | − .011 |
| 35. Terre Haute, Ind. | 39 28.7 | 87 23.8 | 151 | 980.119 | − .047 | + .001 | 980.073 | 980.072 | − .001 |
| 36. Chicago, Ill. | 41 47.4 | 87 36.1 | 182 | 980.326 | − .056 | + .007 | 980.277 | 980.278 | + .001 |
| 37. Madison, Wis. | 43 04.6 | 89 24.0 | 270 | 980.442 | − .083 | + .003 | 980.362 | 980.365 | + .003 |
| 38. St. Louis, Mo. | 38 38.0 | [illegible] 12.2 | 154 | 980.045 | − .048 | + .001 | 979.998 | 980.001 | + .003 |
| 39. Kansas City, Mo. | 39 05.8 | 94 35.4 | 278 | 980.085 | − .086 | − .001 | 979.998 | 979.990 | − .008 |
| 40. Ellsworth, Kans. | 38 43.7 | 98 13.5 | 469 | 980.053 | − .145 | − .004 | 979.904 | 979.926 | + .022 |
| 41. Wallace, Kans. | 38 54.7 | 101 35.4 | 1,005 | 980.069 | − .310 | .000 | 979.759 | 979.755 | − .004 |
| 42. Colorado Springs, Colo. | 38 50.7 | 104 49.0 | 1,841 | 980.064 | − .568 | − .007 | 979.489 | 979.490 | + .001 |
| 43. Pikes Peak, Colo. | 38 50.3 | 105 02.0 | 4,293 | 980.063 | −1.325 | + .187 | 978.925 | 978.954 | + .029 |
| 44. Denver, Colo. | 39 40.6 | 104 56.9 | 1,638 | 980.137 | − .505 | − .015 | 979.617 | 979.609 | − .008 |
| 45. Gunnison, Colo. | 38 32.6 | 106 56.0 | 2,340 | 980.037 | − .722 | − .001 | 979.314 | 979.342 | + .028 |
| 46. Grand Junction, Colo. | 39 04.2 | 108 33.9 | 1,398 | 980.083 | − .431 | − .051 | 979.601 | 979.633 | + .032 |
| 47. Green River, Utah | 38 59.4 | 110 09.9 | 1,243 | 980.076 | − .384 | − .043 | 979.649 | 979.636 | − .013 |
| 48. Pleasant Valley Junction, Utah | 39 50.8 | 111 00.8 | 2,191 | 980.152 | − .676 | + .024 | 979.500 | 979.512 | + .012 |
| 49. Salt Lake City, Utah | 40 46.1 | 111 53.8 | 1,322 | 980.234 | − .408 | − .041 | 979.785 | 979.803 | + .018 |
| 50. Grand Canyon, Wyo. | 44 43.3 | 110 29.7 | 2,386 | 980.591 | − .736 | + .038 | 979.893 | 979.899 | + .006 |
| 51. Norris Geyser Basin, Wyo. | 44 44.2 | 110 42.0 | 2,276 | 980.592 | − .702 | + .031 | 979.921 | 979.950 | + .029 |
| 52. Lower Geyser Basin, Wyo. | 44 33.4 | 110 48.1 | 2,200 | 980.576 | − .679 | + .028 | 979.925 | 979.932 | + .007 |
| 53. Seattle, Wash. (university) | 47 39.6 | 122 18.3 | 58 | 980.856 | − .018 | − .020 | 980.818 | 980.733 | − .085 |
| 54. San Francisco, Cal. | 37 47.5 | 122 25.7 | 114 | 979.970 | − .035 | + .045 | 979.980 | 979.965 | − .015 |
| 55. Mount Hamilton, Cal. | 37 20.4 | 121 38.6 | 1,282 | 979.931 | − .396 | + .120 | 979.655 | 979.660 | + .005 |
| 56. Seattle, Wash. (high school) | 47 36.5 | 122 19.8 | 74 | 980.851 | − .023 | − .018 | 980.810 | 980.725 | − .085 |
| 57. Iron River, Mich. | 46 05.4 | 88 38.4 | 458 | 980.714 | − .141 | + .014 | 980.587 | 980.633 | + .046 |
| 58. Ely, Minn. | 47 48.6 | 92 01.0 | 448 | 980.870 | − .138 | + .008 | 980.740 | 980.771 | + .031 |
| 59. Pembina, N. Dak. | 48 58.1 | 97 14.9 | 243 | 980.974 | − .075 | − .009 | 980.890 | 980.917 | + .027 |
| 60. Mitchell, S. Dak. | 43 41.8 | 98 01.8 | 408 | 980.498 | − .126 | − .006 | 980.366 | 980.375 | + .009 |
| 61. Sweetwater, Tex. | 32 28.4 | 100 24.1 | 655 | 979.519 | − .202 | + .009 | 979.326 | 979.305 | − .021 |
| 62. Kerrville, Tex. | 30 01.3 | 99 07.6 | 498 | 979.323 | − .154 | + .013 | 979.182 | 979.221 | + .039 |
| 63. El Paso, Tex. | 31 46.3 | 106 29.0 | 1,146 | 979.462 | − .354 | + .001 | 979.109 | 979.124 | + .015 |
| 64. Nogales, Ariz. | 31 21.3 | 110 56.6 | 1,181 | 979.429 | − .364 | + .038 | 979.103 | 979.061 | − .042 |
| 65. Yuma, Ariz. | 32 43.3 | 114 37.0 | 54 | 979.539 | − .017 | − .010 | 979.512 | 979.529 | + .017 |
| 66. Compton, Cal. | 33 53.4 | 118 13.2 | 20 | 979.636 | − .006 | .000 | 979.630 | 979.588 | − .042 |
| 67. Goldfield, Nev. | 37 42.2 | 117 14.5 | 1,716 | 979.963 | − .529 | + .027 | 979.461 | 979.456 | − .005 |
| 68. Yavapai, Ariz. | 36 03.9 | 112 07.1 | 2,179 | 979.821 | − .672 | + .034 | 979.183 | 979.192 | + .009 |
| 69. Grand Canyon, Ariz. | 36 05.3 | 112 06.8 | 849 | 979.823 | − .262 | − .096 | 979.465 | 979.463 | − .002 |
| 70. Gallup, N. Mex. | 35 31.8 | 108 44.2 | 1,990 | 979.775 | − .614 | + .014 | 979.175 | 979.170 | − .005 |
| 71. Las Vegas, N. Mex. | 35 35.8 | 105 12.1 | 1,960 | 979.781 | − .605 | + .017 | 979.193 | 979.204 | + .011 |
| 72. Shamrock, Tex. | 35 12.8 | 100 11.4 | 708 | 979.748 | − .218 | + .007 | 979.537 | 979.577 | + .040 |
| 73. Denison, Tex. | 33 45.3 | 96 32.8 | 230 | 979.625 | − .071 | − .001 | 979.553 | 979.566 | + .013 |
| 74. Minneapolis, Minn. | 44 58.7 | 93 13.9 | 256 | 980.614 | − .079 | − .005 | 980.530 | 980.597 | + .067 |
| 75. Lead, S. Dak. | 44 21.1 | 103 45.6 | 1,590 | 980.557 | − .491 | + .044 | 980.110 | 980.170 | + .060 |
| 76. Bismarck, N. Dak. | 46 48.5 | 100 47.0 | 516 | 980.779 | − .159 | − .005 | 980.615 | 980.625 | + .010 |
| 77. Hinsdale, Mont. | 48 23.8 | 107 05.3 | 661 | 980.923 | − .204 | − .017 | 980.702 | 980.739 | + .037 |
| 78. Sandpoint, Idaho. | 48 16.4 | 116 33.3 | 637 | 980.911 | − .197 | − .044 | 980.670 | 980.680 | + .010 |
| 79. Boise, Idaho | 43 37.2 | 116 12.3 | 821 | 980.491 | − .253 | − .042 | 980.196 | 980.212 | + .016 |

*Table of principal facts for 124 gravity stations in the United States*—Continued.

| Number and name of station | φ | λ | H | $\gamma_0$ | Correction for elevation | Correction for topography and compensation | Computed gravity at station ($g_c$) | Observed gravity at station ($g$) | ($g-g_c$) |
|---|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | *Meters.* | | | | | | |
| 80. Astoria, Oreg. | 46 11.3 | 123 50.2 | 1 | 980.724 | 0.000 | +0.008 | [redacted] | [redacted] | −0.005 |
| 81. Sisson, Cal. | 41 18.3 | 122 19.6 | 1,048 | 980.282 | − .323 | + .015 | 979.974 | 979.972 | − .002 |
| 82. Rock Springs, Wyo. | 41 35.1 | 109 13.2 | 1,910 | 980.308 | − .589 | − .001 | 979.718 | 979.739 | + .021 |
| 83. Paxton, Nebr. | 41 07.4 | 101 21.3 | 932 | 980.266 | − .288 | + .002 | 979.980 | [redacted] | + .002 |
| 84. Washington, D. C. (Bureau of Standards) | 38 56.3 | 77 04.0 | 103 | 980.070 | − .032 | + .012 | 980.050 | [redacted] | + .045 |
| 85. North Hero, Vt. | 44 49.1 | 73 17.5 | 35 | 980.599 | − .011 | − .009 | 980.579 | [redacted] | + .009 |
| 86. Lake Placid, N. Y. | 44 17.5 | 73 59.1 | 571 | 980.551 | − .176 | + .032 | 980.407 | 980.421 | + .014 |
| 87. Potsdam, N. Y. | 44 40.1 | 74 58.8 | 130 | 980.586 | − .040 | − .004 | [redacted] | 980.571 | + .029 |
| 88. Wilson, N. Y. | 43 18.4 | 78 49.6 | 87 | 980.462 | − .027 | − .002 | [redacted] | 980.431 | − .002 |
| 89. Alpena, Mich. | 45 03.8 | 83 27.0 | 178 | 980.622 | − .055 | .000 | [redacted] | [redacted] | − .012 |
| 90. Virginia Beach, Va. | 36 50.5 | 75 58.4 | 4 | 979.888 | − .001 | + .025 | 979.912 | 979.872 | − .040 |
| 91. Durham, N. C. | 36 00.2 | 78 53.5 | 126 | 979.816 | − .039 | + .014 | 979.791 | 979.835 | + .044 |
| 92. Fernandina, Fla. | 30 40.2 | 81 27.7 | 3 | 979.374 | − .001 | + .017 | [redacted] | 979.408 | + .018 |
| 93. Wilmer, Ala. | 30 49.2 | 88 20.5 | 69 | 979.386 | − .021 | + .018 | 979.383 | 979.347 | − .036 |
| 94. Aliceville, Ala. | 33 07.6 | [redacted] 10.8 | 61 | 979.572 | − .019 | + .008 | 979.561 | 979.552 | − .009 |
| 95. New Madrid, Mo. | 36 35.5 | 89 31.6 | 79 | 979.867 | − .024 | + .001 | 979.844 | 979.853 | + .009 |
| 96. Mena, Ark. | 34 35.2 | 94 14.6 | 368 | 979.695 | − .114 | + .015 | 979.596 | 979.552 | − .044 |
| 97. Nacogdoches, Tex. | 31 36.2 | 94 37.8 | 92 | 979.448 | − .029 | + .008 | 979.427 | 979.424 | − .003 |
| 98. Alpine, Tex. | 30 21.5 | 103 39.7 | 1,359 | 979.349 | − .420 | + .033 | 978.962 | 978.991 | + .029 |
| 99. Farwell, Tex. | 34 23.2 | 103 01.8 | 1,259 | 979.678 | − .388 | + .011 | 979.301 | 979.293 | − .008 |
| 100. Guymon, Okla. | 36 40.7 | 101 28.7 | 949 | 979.874 | − .293 | − .001 | 979.580 | 979.571 | − .009 |
| 101. Helenwood, Tenn. | 36 25.9 | 84 32.6 | 422 | 979.853 | − .130 | + .015 | 979.738 | 979.786 | + .048 |
| 102. Cloudland, Tenn. | 36 06.2 | 82 07.9 | 1,890 | 979.824 | − .583 | + .130 | 979.371 | 979.383 | + .012 |
| 103. Hughes, Tenn. | 38 08.5 | 82 07.2 | 994 | 979.827 | − .306 | + .053 | 979.574 | 979.553 | − .021 |
| 104. Charleston, W. Va. | 38 20.9 | 81 37.7 | 184 | 980.019 | − .057 | − .010 | 979.952 | 979.936 | − .016 |
| 105. State College, Pa. | [redacted] 47.9 | 77 51.8 | 358 | 980.237 | − .110 | + .010 | 980.137 | 980.124 | − .013 |
| 106. Fort Kent, Me. | 47 14.9 | 68 36.0 | 160 | 980.818 | − .049 | + .001 | 980.770 | [redacted] | − .005 |
| 107. Prentice, Wis. | 45 32.6 | 90 17.8 | 469 | 980.665 | − .145 | + .010 | 980.530 | 980.562 | + .032 |
| 108. Fergus Falls, Minn. | 46 17.2 | 96 05.0 | 366 | 980.732 | − .113 | + .001 | 980.620 | [redacted] | + .002 |
| 109. Sheridan, Wyo. | 44 48.0 | 106 58.7 | 1,150 | 980.598 | − .355 | − .031 | 980.212 | 980.252 | + .040 |
| 110. Boulder, Mont. | 46 14.2 | 112 07.3 | 1,493 | 980.727 | − .461 | − .007 | 980.259 | 980.252 | − .007 |
| 111. Skykomish, Wash. | 47 42.4 | 121 22.3 | 280 | 980.860 | − .086 | − .047 | 980.727 | 980.707 | − .020 |
| 112. Olympia, Wash. | 47 03.4 | 122 52.7 | 19 | 980.802 | − .006 | − .012 | 980.784 | 980.825 | + .041 |
| 113. Heppner, Oreg. | 45 21.4 | 119 33.2 | 598 | 980.648 | − .185 | − .007 | 980.456 | 980.437 | − .019 |
| 114. Truckee, Cal. | 39 19.6 | 120 11.4 | 1,805 | 980.105 | − .557 | + .057 | 979.605 | 979.585 | − .020 |
| 115. Winnemucca, Nev. | 40 58.4 | 117 43.8 | 1,311 | 980.253 | − .404 | − .004 | 979.845 | 979.844 | − .001 |
| 116. Ely, Nev. | 39 14.9 | 114 53.4 | 1,962 | 980.099 | − .605 | + .020 | 979.514 | 979.501 | − .013 |
| 117. Guernsey, Wyo. | 42 16.1 | 104 44.0 | 1,322 | 980.369 | − .408 | − .016 | 979.945 | 979.989 | + .044 |
| 118. Pierre, S. Dak. | 44 21.9 | 100 20.8 | 454 | 980.558 | − .140 | − .013 | 980.405 | 980.427 | + .022 |
| 119. Fort Dodge, Iowa. | 42 30.8 | 94 11.4 | 340 | 980.391 | − .105 | + .002 | 980.288 | 980.311 | + .023 |
| 120. Keithsburg, Ill. | 41 06.4 | 90 57 | 167 | 980.265 | − .051 | − .003 | 980.211 | 980.211 | [redacted] |
| 121. Grand Rapids, Mich. | 42 58.0 | 85 40.8 | 236 | 980.432 | − .073 | + .003 | 980.362 | 980.372 | + .010 |
| 122. Angola, Ind. | 41 37.7 | 85 00.6 | 318 | 980.312 | − .098 | + .011 | 980.225 | 980.244 | + .019 |
| 123. Albany, N. Y. | 42 39.1 | 73 46.1 | 61 | 980.404 | − .019 | − .006 | 980.379 | 980.344 | − .035 |
| 124. Port Jervis, N. Y. | 41 22.4 | 74 41.1 | 141 | 980.288 | − .044 | + .003 | 980.247 | 980.222 | − .025 |

## CORRECTION TO HELMERT'S FORMULA OF 1901.

The mean of the above values of $g-g_c$ is +0.006 dyne and the probable error of a single value is ±0.017 dyne. The two residuals from this mean for the two Seattle stations are each −0.091 dyne, which is more than five times the probable error of a single value. It is believed that these anomalies are caused by some very unusual local disturbance and consequently should be rejected from the list of anomalies before taking means.

After rejecting the two Seattle stations the probable error of a single value of $g-g_c$ is ±0.016 dyne. The mean value of $g-g_c$ with regard to sign is +0.008 ±0.0014 dyne. As this mean is five times its own probable error it is believed that it represents a real correction to the Helmert formula of 1901 for the theoretical value of gravity at sea level, and that this correction should be applied in connection with the new method of reduction for topography and compensation. Accordingly in the following tables the quantities called "Anomaly, New method" are $g-(g_c+0.008)$ in dynes. These are, therefore, the anomalies in gravity as given by the new method and referred to the following formula for the theoretical value of gravity at sea level:

$$\gamma_0 = 978.038\ (1 + 0.005302 \sin^2 \varphi - 0.000007 \sin^2 2\varphi),$$

this being Helmert's formula of 1901 (for the Potsdam system) with a constant correction of +0.008 to the first term. This is equivalent to changing Helmert's derived value of gravity at the equator but with his flattening retained. The reciprocal of the flattening as derived from gravity observations in the United States is given on page 25.

A plus sign of the anomaly means that at the station in question the intensity of gravity is in excess of that which would occur there if the isostatic compensation were complete and uniformly distributed to the depth of 113.7 kilometers, while if the anomaly is minus the intensity of gravity is less than it would be if the compensation were complete and uniformly distributed to the depth of 113.7 kilometers.

## COMPARISON OF APPARENT ANOMALIES BY THE NEW AND OLD METHODS.

The values $g_o'' - \gamma_o$ and of $g_o - \gamma_o$ in the following tables have the same meaning as in the reports of the International Geodetic Association.

The quantity $g_o'' - \gamma_o$ is the apparent anomaly when the Helmert formula of 1901 and the Bouguer reduction are used. The Bouguer reduction "has been very generally applied in reducing pendulum observations to the level of the sea. This formula is $dg = +\frac{2gH}{r}\left(1 - \frac{3\delta}{4\Delta}\right)$, where $dg$ is the correction to observed gravity, $g$ is gravity at sea level, $H$ is elevation above sea level, $r$ is radius of the earth, $\delta$ is density of matter lying above sea level, and $\Delta$ is mean density of the earth. The first term takes account of the distance from the earth's center, and the second term of the vertical attraction of the matter lying between the sea level and station, on the supposition that the latter is located on an indefinitely extended horizontal plain. Wherever the topography about a station departs materially from this condition of a horizontal plain a third term must be added to the above formula, being a correction to the second term or to observed gravity on account of such irregularities."[1] The Bouguer reduction thus takes no account of isostatic compensation and neglects all curvature of the sea-level surface, the topography being treated as if it were standing on a plane of indefinite extent.

The quantity $g_o - \gamma_o$ is the apparent anomaly when the Helmert formula of 1901 is used in connection with the so-called reduction to sea level in free air only (0.0003086 $H$). This reduction ignores both the topography and the isostatic compensation. It takes account simply of the increased distance of the station from the earth's center when the station is above sea level.

A comparison of the anomalies by the new method, on the one hand, with those by the two older methods, as shown in the columns headed $g_o'' - \gamma_o$, and $g_o - \gamma_o$, on the other hand, will therefore show the merits of the new method of reduction in comparison with the Bouguer and the free-air methods.

The comparison of the new method is made with the Bouguer and free-air reductions, for the Bouguer reduction postulates a total lack of compensation and a consequent high rigidity of the earth's crust while the free-air method assumes that each piece of topography is completely compensated for at zero depth. Besides, the Bouguer and free-air methods are those which are now most generally used.

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[1] This excellent statement of the nature of the Bouguer reduction is quoted from Mr. G. R. Putnam. (See Appendix 1 of the Coast and Geodetic Survey Report for 1894, pp. 21–22.)

| Number and name of station | Anomaly | | |
|---|---|---|---|
| | New method $g-(g_c+0.008)$ | Bouguer $(g_o''-\gamma_o)$ | In free air $(g_o-\gamma_o)$ |
| 1. Key West, Fla. | +0.008 | +0.048 | +0.048 |
| 2. West Palm Beach, Fla. | + .018 | + .057 | + .057 |
| 3. Punta Gorda, Fla. | + .010 | + .038 | + .038 |
| 4. Apalachicola, Fla. | 000 | + .023 | + .023 |
| 5. New Orleans, La. | − .013 | + .008 | + .008 |
| 6. Rayville, La. | + .016 | + .029 | + .032 |
| 7. Galveston, Tex. | − .009 | + .006 | + .006 |
| 8. Point Isabel, Tex. | + .027 | + .049 | + .050 |
| 9. Laredo, Tex. | − .020 | − .022 | − .009 |
| 10. Austin, Tex. (capitol) | − .008 | − .021 | − .003 |
| 11. Austin, Tex. (university) | − .010 | − .023 | − .003 |
| 12. McAlester, Okla. | − .027 | − .045 | − .018 |
| 13. Little Rock, Ark. | + .030 | + .030 | + .039 |
| 14. Columbia, Tenn. | + .026 | + .017 | + .040 |
| 15. Atlanta, Ga. | − .023 | − .036 | − .001 |
| 16. McCormick, S. C. | + .015 | + .017 | + .035 |
| 17. Charleston, S. C. | − .021 | + .003 | + .003 |
| 18. Beaufort, N. C. | − .021 | + .023 | + .023 |
| 19. Charlottesville, Va. | − .013 | − .021 | − .003 |
| 20. Deer Park, Md. | + .010 | − .019 | + .059 |
| 21. Washington, D. C. (Coast and Geodetic Survey Office) | + .037 | + .048 | + .049 |
| 22. Washington, D. C. (Smithsonian Institution) | + .039 | + .049 | + .050 |
| 23. Baltimore, Md. | − .011 | 000 | + .003 |
| 24. Philadelphia, Pa. | + .022 | + .037 | + .039 |
| 25. Princeton, N. J. | − .019 | − .004 | + .002 |
| 26. Hoboken, N. J. | + .024 | + .039 | + .040 |
| 27. New York, N. Y. | + .022 | + .037 | + .041 |
| 28. Worcester, Mass. | − .020 | − .014 | + .006 |
| 29. Boston, Mass. | + .005 | + .024 | + .026 |
| 30. Cambridge, Mass. | + .005 | + .022 | + .023 |
| 31. Calais, Me. | − .008 | + .006 | + .010 |
| 32. Ithaca, N. Y. | − .023 | − .033 | − .010 |
| 33. Cleveland, Ohio. | − .003 | − .016 | + .005 |
| 34. Cincinnati, Ohio. | − .019 | − .034 | − .009 |
| 35. Terre Haute, Ind. | − .009 | − .016 | 000 |
| 36. Chicago, Ill. | − .007 | − .012 | + .008 |
| 37. Madison, Wis. | − .005 | − .024 | + .006 |
| 38. St. Louis, Mo. | − .005 | − .014 | + .004 |
| 39. Kansas City, Mo. | − .016 | − .038 | − .009 |
| 40. Ellsworth, Kans. | + .014 | − .029 | + .016 |
| 41. Wallace, Kans. | − .012 | − .105 | − .004 |
| 42. Colorado Springs, Colo. | − .007 | − .188 | − .006 |
| 43. Pikes Peak, Colo. | + .021 | − .204 | + .216 |
| 44. Denver, Colo. | − .016 | − .182 | − .023 |
| 45. Gunnison, Colo. | + .020 | − .229 | + .027 |
| 46. Grand Junction, Colo. | + .024 | − .158 | − .019 |
| 47. Green River, Utah. | − .021 | − .180 | − .056 |
| 48. Pleasant Valley Junction, Utah | + .004 | − .187 | + .036 |
| 49. Salt Lake City, Utah. | + .010 | − .146 | − .023 |
| 50. Grand Canyon, Wyo. | − .002 | − .208 | + .044 |
| 51. Norris Geyser Basin, Wyo. | + .021 | − .177 | + .060 |
| 52. Lower Geyser Basin, Wyo. | − .001 | − .193 | + .035 |
| 53. Seattle, Wash. (university) | − .093 | − .111 | − .105 |
| 54. San Francisco, Cal. | − .023 | + .019 | + .004 |
| 55. Mount Hamilton, Cal. | − .003 | + .003 | + .125 |
| 56. Seattle, Wash. (high school) | − .093 | − .111 | − .103 |
| 57. Iron River, Mich. | + .038 | + .009 | + .060 |
| 58. Ely, Minn. | + .023 | − .010 | + .039 |
| 59. Pembina N. Dak. | + .019 | − .008 | + .018 |
| 60. Mitchell, S. Dak. | + .001 | − .040 | + .003 |
| 61. Sweetwater, Tex. | − .029 | − .084 | − .012 |
| 62. Kerrville, Tex. | + .031 | − .003 | + .052 |
| 63. El Paso, Tex. | + .007 | − .111 | + .016 |
| 64. Nogales, Ariz. | − .030 | − .132 | − .004 |
| 65. Yuma, Ariz. | + .009 | + .001 | + .007 |
| 66. Compton, Cal. | − .050 | − .041 | − .042 |
| 67. Goldfield, Nev. | − .013 | − .166 | + .022 |
| 68. Yavapai, Ariz. | + .001 | − .162 | + .043 |
| 69. Grand Canyon, Ariz. | − .010 | − .173 | − .098 |
| 70. Gallup, N. Mex. | − .013 | − .211 | + .009 |
| 71. Las Vegas, N. Mex. | + .003 | − .189 | + .028 |
| 72. Shamrock, Tex. | + .032 | − .031 | + .047 |
| 73. Denison, Tex. | + .005 | − .012 | + .012 |
| 74. Minneapolis, Minn. | + .059 | + .034 | + .062 |
| 75. Lead, S. Dak. | + .052 | − .072 | + .104 |
| 76. Bismarck, N. Dak. | + .002 | − .052 | + .005 |
| 77. Hinsdale, Mont. | + .029 | − .053 | + .020 |
| 78. Sandpoint, Idaho | + .002 | − .105 | − .034 |
| 79. Boise, Idaho | + .008 | − .117 | − .026 |
| 80. Astoria, Oreg. | − .013 | + .003 | + .003 |
| 81. Sisson, Cal. | − .010 | − .103 | + .013 |
| 82. Rock Springs, Wyo. | + .013 | − .191 | + .020 |
| 83. Paxton, Nebr. | − .006 | − .099 | + .004 |
| 84. Washington, D. C. (Bureau of Standards) | + .037 | + .046 | + .057 |
| 85. North Hero. Vt. | + .001 | − .004 | 000 |
| 86. Lake Placid, N. Y. | + .006 | − .017 | + .046 |
| 87. Potsdam, N. Y. | + .021 | + .011 | + .025 |
| 88. Wilson, N. Y. | − .010 | − .014 | − .004 |
| 89. Alpena, Mich. | − .020 | − .032 | − .012 |
| 90. Virginia Beach, Va. | − .048 | − .015 | − .015 |
| 91. Durham, N. C. | + .036 | + .045 | + .058 |
| 92. Fernandina, Fla. | + .010 | + .036 | + .035 |
| 93. Wilmer, Ala. | − .044 | − .027 | − .018 |
| 94. Aliceville, Ala. | − .017 | − .010 | − .001 |
| 95. New Madrid, Mo. | + .001 | + .001 | + .010 |
| 96. Mena, Ark. | − .052 | − .066 | − .029 |
| 97. Nacogdoches, Tex. | − .011 | − .005 | + .005 |
| 98. Alpine, Tex. | + .021 | − .088 | + .062 |
| 99. Farwell, Tex. | − .016 | − .132 | + .003 |
| 100. Guymon, Okla. | − .017 | − .110 | − .010 |
| 101. Helenwood, Tenn. | + .040 | + .015 | + .063 |
| 102. Cloudland, Tenn. | + .004 | − .042 | + .142 |
| 103. Hughes, Tenn. | − .029 | − .074 | + .032 |
| 104. Charleston. W. Va. | − .024 | − .045 | − .026 |
| 105. State College, Pa. | − .021 | − .038 | − .003 |
| 106. Fort Kent, Me. | − .013 | − .021 | − .004 |
| 107. Prentice, Wis. | + .024 | − .005 | + .042 |
| 108. Fergus Falls, Minn. | − .006 | − .034 | + .003 |
| 109. Sherdian, Wyo. | + .032 | − .116 | + .009 |
| 110. Boulder, Mont. | − .015 | − .181 | − .014 |
| 111. Skykomish, Wash. | − .028 | − .087 | − .067 |
| 112. Olympia, Wash. | + .033 | + .026 | + .029 |
| 113. Heppner, Oreg. | − .027 | − .093 | − .026 |
| 114. Truckee, Cal. | − .028 | − .162 | + .037 |
| 115. Winnemucca, Nev. | − .009 | − .150 | − .005 |
| 116. Ely, Nev. | − .021 | − .207 | + .007 |
| 117. Guernsey, Wyo. | + .036 | − .113 | + .028 |
| 118. Pierre, S. Dak. | + .014 | − .039 | + .009 |
| 119. Fort Dodge, Iowa | + .015 | − .011 | + .025 |
| 120. Keithsburg, Ill. | − .008 | − .018 | − .003 |
| 121. Grand Rapids, Mich. | + .002 | − .008 | + .013 |
| 122. Angola, Ind. | + .011 | − .001 | + .030 |
| 123. Albany, N. Y. | − .043 | − .048 | − .041 |
| 124. Port Jervis, N. Y. | − .033 | − .035 | − .022 |

For all the stations treated as a single group the means are as follows:

| | Anomaly | | |
|---|---|---|---|
| | New method | Bouguer | In free air |
| Mean with regard to sign 124 stations | −0.002 | −0.050 | +0.014 |
| Mean without regard to sign 124 stations | .020 | .064 | .029 |
| Mean with regard to sign 122 stations (Seattle stations omitted) | .000 | − .048 | + .016 |
| Mean without regard to sign 122 stations (Seattle stations omitted) | .018 | .063 | .028 |

The mean without regard to sign for the new-method anomalies is only two-thirds that for the free-air anomalies and about three-tenths that for the Bouguer anomalies. At most of the stations the new-method anomalies are smaller than the free-air and the Bouguer anomalies.

The maximum new-method anomaly is −0.093 at the Seattle stations, Nos. 53 and 56, while the maximum free-air anomaly is +0.216 at station 43 (Pikes Peak) and the maximum Bouguer anomaly is −0.229 at station 45 (Gunnison).

An analysis of the above tables indicates clearly that the new method of reduction is much closer to the truth than either the Bouguer or the free-air methods of reduction.

The distribution, according to size, of the anomalies by the three methods of reduction is shown in the following table:

| Limits in dynes | Number of anomalies | | | Limits in dynes | Number of anomalies | | |
|---|---|---|---|---|---|---|---|
| | New method | Bouguer | In free air | | New method | Bouguer | In free air |
| 0. 200 to 0. 300 | 0 | 5 | 1 | 0. 050 to 0. 060 | 5 | 3 | 8 |
| 0. 100 to 0. 200 | 0 | 28 | 5 | 0. 040 to 0. 050 | 4 | 12 | 12 |
| 0. 090 to 0. 100 | 2 | 2 | 1 | 0. 030 to 0. 040 | 12 | 17 | 13 |
| 0. 080 to 0. 090 | 0 | 3 | 0 | 0. 020 to 0. 030 | 32 | 14 | 20 |
| 0. 070 to 0. 080 | 0 | 2 | 0 | 0. 010 to 0. 020 | 34 | 19 | 17 |
| 0. 060 to 0. 070 | 0 | 1 | [illegible] | 0. 000 to 0. 010 | 35 | 18 | 41 |

An inspection of the data in this table shows that the anomalies of the new method are distributed in fair agreement with the law of distribution of accidental errors. There is no indication of any decided systematic error for those anomalies. On the other hand, the distribution of the anomalies by each of the older methods of reduction departs greatly from the law of distribution of accidental errors and indicates that there are substantial systematic errors present.

## DISCUSSION OF ERRORS.

It is important to know the degree of reliability of the values of gravity at the stations used in this investigation in order to be able to estimate the extent to which errors from different sources may affect the apparent anomalies. The subject of the errors and their effects on the anomalies is dealt with exhaustively in Special Publication No. 10, and here only a summary of what was stated there will be given.

The value of the intensity of gravity at a station is subject to uncertainties on account of the observations which are represented by a probable error of ±0.0018 dyne on an average. It is probable that at no station is the actual error from this source greater than 0.0072 dyne. There are also small errors present in each of the operations necessary in the computations of the gravity anomalies. The methods adopted in the computing practically eliminate any systematic errors and those remaining must be considered as belonging to the accidental class. The errors from the several sources are nearly or quite independent of each other and follow different laws of distribution. In estimating the effects of all these errors at a station one must therefore consider them as accidental errors and that their combined effect is the square root of the sum of their squares rather than merely their sum. On this basis it is estimated that the probable error of the computed anomaly at a station by the new method is about ±0.003 dyne on an average. In other words, the chances are even for and against the proposition, that the actual error in the computed anomaly at a station is greater than 0.003 dyne. The new method of reduction is not subject to hidden or unsuspected errors which would vitiate the results.

## POSSIBLE RELATIONS OF ANOMALIES TO TOPOGRAPHY.

In the following five tables the stations are arranged in groups according to the topography near the station in order to learn whether there are relations between the anomalies and the topography. It is important to test the new-method anomalies in this way to ascertain whether they follow in size and sign the relations known to exist between the topography and the anomalies by the two older methods of reduction.

*Eighteen coast stations, in the order of their distances from the 1000-fathom line.*

| Number and name of station | Distance from 1000-fathom line | Anomaly | | |
|---|---|---|---|---|
| | | New method $g-(g_c+0.008)$ | Bouguer $(g_0''-\gamma_0)$ | In free air $(g_0-\gamma_0)$ |
| | *Kilometers* | | | |
| 54. San Francisco, Cal. | 85 | −0.023 | +0.019 | +0.004 |
| 18. Beaufort, N. C. | 95 | − .021 | + .023 | + .023 |
| 80. Astoria, Oreg. | 120 | − .013 | + .003 | + .003 |
| 90. Virginia Beach, Va. | 130 | − .048 | − .015 | − .015 |
| 92. Fernandina, Fla. | 145 | + .010 | + .036 | + .035 |
| 1. Key West, Fla. | 150 | + .008 | + .048 | + .048 |
| 8. Point Isabel, Tex. | 160 | + .027 | + .049 | + .050 |
| 5. New Orleans, La. | 210 | − .013 | + .008 | + .008 |
| 4. Apalachicola, Fla. | 225 | .000 | + .023 | + .023 |
| 27. New York, N. Y. | 225 | + .022 | + .037 | + .041 |
| 26. Hoboken, N. J. | 230 | + .024 | + .039 | + .040 |
| 66. Compton, Cal. | 230 | − .050 | − .041 | − .042 |
| | *Kilometers* | | | |
| 2. West Palm Beach, Fla. | 243 | +0.018 | +0.057 | +0.057 |
| 3. Punta Gorda, Fla. | 280 | + .010 | + .038 | + .038 |
| 29. Boston, Mass. | 300 | + .005 | + .024 | + .026 |
| 30. Cambridge, Mass. | 300 | + .005 | + .022 | + .023 |
| 17. Charleston, S. C. | 305 | − .021 | + .003 | + .003 |
| 7. Galveston, Tex. | 330 | − .009 | + .006 | + .006 |
| Mean with regard to sign | | − .004 | + .021 | + .021 |
| Mean without regard to sign | | .018 | .027 | .027 |

*Twenty-five stations near the coast, in the order of their distances from the open coast.*

| Number and name of station | Distance from the open coast | Anomaly | | |
|---|---|---|---|---|
| | | New method $g-(g_c+0.008)$ | Bouguer $(g_0''-\gamma_0)$ | In free air $(g_0-\gamma_0)$ |
| | *Kilometers* | | | |
| 31. Calais, Me. | 50 | −0.008 | +0.006 | +0.010 |
| 25. Princeton, N. J. | 60 | − .019 | − .004 | + .002 |
| 93. Wilmer, Ala. | 65 | − .044 | − .027 | − .018 |
| 23. Baltimore, Md. | 75 | − .011 | .000 | + .003 |
| 28. Worcester, Mass. | 85 | − .020 | − .014 | + .006 |
| 24. Philadelphia, Pa. | 90 | + .022 | + .037 | + .039 |
| 124. Port Jervis, N. Y. | 100 | − .033 | − .035 | − .022 |
| 81. Sisson, Cal. | 142 | − .010 | − .103 | + .013 |
| 21. Washington, D. C. (Coast and Geodetic Survey Office) | 170 | + .037 | + .048 | + .049 |
| 22. Washington, D. C. (Smithsonian Institution) | 170 | + .039 | + .049 | + .050 |
| 84. Washington, D. C. (Bureau of Standards) | 175 | + .037 | + .046 | + .057 |
| 91. Durham, N. C. | 210 | + .036 | + .045 | + .058 |
| 9. Laredo, Tex. | 215 | − .020 | − .022 | − .009 |
| | *Kilometers* | | | |
| 65. Yuma, Ariz. | 220 | +0.009 | +0.001 | +0.007 |
| 97. Nacogdoches, Tex. | 220 | − .011 | − .005 | + .005 |
| 123. Albany, N. Y. | 220 | − .043 | − .048 | − .041 |
| 16. McCormick, S. C. | 235 | + .015 | + .017 | + .035 |
| 10. Austin, Tex. (capitol) | 245 | − .008 | − .021 | − .003 |
| 11. Austin, Tex. (university) | 245 | − .010 | − .023 | − .003 |
| 19. Charlottesville, Va. | 250 | − .013 | − .021 | − .003 |
| 32. Ithaca, N. Y. | 305 | − .023 | − .033 | − .010 |
| 94. Aliceville, Ala. | 305 | − .017 | − .010 | − .001 |
| 62. Kerrville, Tex. | 310 | + .031 | − .003 | + .052 |
| 106. Fort Kent, Me. | 315 | − .013 | − .021 | − .004 |
| 6. Rayville, La. | 325 | + .016 | + .029 | + .032 |
| Mean with regard to sign | | − .002 | − .004 | + .012 |
| Mean without regard to sign | | .022 | .027 | .021 |

*Thirty-nine stations in the interior and not in mountainous regions, arranged in the order of elevation.*

| Number and name of station | Elevation | Anomaly | | |
|---|---|---|---|---|
| | | New method $g-(g_c+0.008)$ | Bouguer $(g_0''-\gamma_0)$ | In free air $(g_0-\gamma_0)$ |
| | *Meters* | | | |
| 95. New Madrid, Mo. | 79 | +0.001 | +0.001 | +0.010 |
| 88. Wilson, N. Y. | 87 | − .010 | − .014 | − .004 |
| 13. Little Rock, Ark. | 89 | + .030 | + .030 | + .039 |
| 87. Potsdam, N. Y. | 130 | + .021 | + .011 | + .025 |
| 35. Terre Haute, Ind. | 151 | − .009 | − .016 | .000 |
| 38. St. Louis, Mo. | 154 | − .005 | − .014 | + .004 |
| 120. Keithsburg, Ill. | 167 | − .008 | − .018 | − .003 |
| 89. Alpena, Mich. | 178 | − .020 | − .032 | − .012 |
| 36. Chicago, Ill. | 182 | − .007 | − .012 | + .008 |
| 104. Charleston, W. Va. | 184 | − .024 | − .045 | − .026 |
| 14. Columbia, Tenn. | 207 | + .026 | + .017 | + .040 |
| 33. Cleveland, Ohio | 210 | − .003 | − .016 | + .005 |
| 73. Denison, Tex. | 230 | + .005 | − .012 | + .012 |
| 121. Grand Rapids, Mich. | 236 | + .002 | − .008 | + .013 |
| 12. McAlester, Okla. | 240 | − .027 | − .045 | − .018 |
| 59. Pembina, N. Dak. | 243 | + .019 | − .008 | + .018 |
| 34. Cincinnati, Ohio | 245 | − .019 | − .034 | − .009 |
| 74. Minneapolis, Minn. | 256 | + .059 | + .034 | + .062 |
| 37. Madison, Wis. | 270 | − .005 | − .024 | + .006 |
| 39. Kansas City, Mo. | 278 | − .016 | − .038 | − .009 |
| 122. Angola, Ind. | 318 | + .011 | − .001 | + .030 |
| 15. Atlanta, Ga. | 324 | − .023 | − .036 | − .001 |
| | *Meters* | | | |
| 119. Fort Dodge, Iowa | 340 | +0.015 | −0.011 | +0.025 |
| 108. Fergus Falls, Minn. | 366 | − .006 | − .034 | + .003 |
| 96. Mena, Ark. | 368 | − .052 | − .066 | − .029 |
| 60. Mitchell, S. Dak. | 408 | + .001 | − .040 | + .003 |
| 58. Ely, Minn. | 448 | + .023 | − .010 | + .039 |
| 118. Pierre, S. Dak. | 454 | + .014 | − .039 | + .009 |
| 57. Iron River, Mich. | 458 | + .038 | + .009 | + .060 |
| 40. Ellsworth, Kans. | 469 | + .014 | − .029 | + .016 |
| 107. Prentice, Wis. | [illegible] | + .024 | − .005 | + .042 |
| 76. Bismarck, N. Dak. | 516 | + .002 | − .052 | + .005 |
| 61. Sweetwater, Tex. | 655 | − .029 | − .084 | − .012 |
| 77. Hinsdale, Mont. | 661 | + .029 | − .053 | + .020 |
| 72. Shamrock, Tex. | 708 | + .032 | − .031 | + .047 |
| 83. Paxton, Nebr. | 932 | − .006 | − .099 | + .004 |
| 100. Guymon, Okla. | 949 | − .017 | − .110 | − .010 |
| 41. Wallace, Kans. | 1005 | − .012 | − .105 | − .004 |
| 99. Farwell, Tex. | 1259 | − .016 | − .132 | + .003 |
| Mean with regard to sign | | + .001 | − .030 | + .011 |
| Mean without regard to sign | | .017 | .035 | 0.18 |

*Twenty-two stations in mountainous regions and below the general level arranged in the order of their distances below the general level.*

| Number and name of station | Average elevation within 100 miles of station minus elevation of station | Elevation of station | Anomaly | | |
|---|---|---|---|---|---|
| | | | New method $g-(\gamma_0+0.008)$ | Bouguer $(g_0''-\gamma_0)$ | In free air $(g_0-\gamma_0)$ |
| | *Meters* | *Meters* | | | |
| 70. Gallup, N. Mex. | 30 | 1990 | −0.013 | −0.211 | +0.009 |
| 105. State College, Pa. | 33 | 358 | − .021 | − .038 | − .003 |
| 67. Goldfield, Nev. | 112 | 1716 | − .013 | − .166 | + .022 |
| 85. North Hero, Vt. | 167 | 35 | + .001 | − .004 | [illegible] |
| 63. El Paso, Tex. | 205 | 1146 | + .007 | − .111 | + .016 |
| 113. Heppner, Oreg. | 264 | 598 | − .027 | − .093 | − .026 |
| 112. Olympia, Wash. | 306 | 19 | + .033 | + .026 | + .029 |
| 110. Boulder, Mont. | 307 | 1493 | − .015 | − .181 | − .014 |
| 111. Skykomish, Wash. | 322 | 280 | − .028 | − .087 | − .067 |
| 117. Guernsey, Wyo. | 324 | 1322 | + .036 | − .113 | + .028 |
| 115. Winnemucca, Nev. | 346 | 1311 | − .009 | − .150 | − .005 |
| 109. Sheridan, Wyo. | 378 | 1150 | + .032 | − .116 | + .009 |
| 82. Rock Springs, Wyo. | 379 | 1910 | + .013 | − .191 | + .020 |
| 45. Gunnison, Colo. | 380 | 2340 | + .020 | − .229 | + .027 |
| 42. Colorado Springs, Colo. | 420 | 1841 | − .007 | − .188 | − .006 |
| 49. Salt Lake City, Utah | 570 | 1322 | +0.010 | −0.146 | −0.023 |
| 44. Denver, Colo. | 574 | 1638 | − .016 | − .182 | − .023 |
| 79. Boise, Idaho | 575 | 821 | + .008 | − .117 | − .026 |
| 78. Sandpoint, Idaho | 588 | 637 | + .002 | − .105 | − .034 |
| 69. Grand Canyon, Ariz. | 824 | [illegible] | − .010 | − .173 | − .098 |
| 46. Grand Junction, Colo. | 850 | 1398 | + .024 | − .158 | − .019 |
| 47. Green River, Utah | 870 | 1243 | − .021 | − .180 | − .056 |
| Mean with regard to sign | | | .000 | − .132 | − .011 |
| Mean without regard to sign | | | .017 | .135 | .025 |

*Eighteen stations in mountainous regions and above the general level arranged in the order of their distances above the general level.*

| Number and name of station | Elevation of station minus average elevation within 100 miles | Elevation of station | Anomaly | | |
|---|---|---|---|---|---|
| | | | New method $g-(g_0+0.008)$ | Bouguer $(g_0''-\gamma_0)$ | In free air $(g_0-\gamma_0)$ |
| | *Meters* | *Meters* | | | |
| 71. Las Vegas, N. Mex. | 18 | 1960 | +0.003 | −0.189 | +0.028 |
| 116. Ely, Nev. | 19 | 1962 | − .021 | − .207 | + .007 |
| 101. Helenwood, Tenn. | 33 | 422 | + .040 | + .015 | + .063 |
| 52. Lower Geyser Basin, Wyo. | [illegible] | 2200 | − .001 | − .193 | + .035 |
| 51. Norris Geyser Basin, Wyo. | 139 | 2276 | + .021 | − .177 | + .060 |
| 48. Pleasant Valley Junction, Utah | 147 | 2191 | + .004 | − .187 | + .036 |
| 50. Grand Canyon, Wyo. | 249 | 2386 | − .002 | − .208 | + .044 |
| 98. Alpine, Tex. | 265 | 1359 | + .021 | − .088 | + .062 |
| 64. Nogales, Ariz. | 288 | 1181 | − .050 | − .132 | − .004 |
| 20. Deer Park, Md. | 291 | 770 | + .010 | − .019 | + .059 |
| 86. Lake Placid, N. Y. | 306 | 571 | +0.006 | −0.017 | +0.046 |
| 103. Hughes, Tenn. | 427 | 994 | − .029 | − .074 | + .032 |
| 75. Lead, S. Dak. | 468 | 1590 | + .052 | − .072 | + .104 |
| 68. Yavapai, Ariz. | 512 | 2179 | + .001 | − .162 | + .043 |
| 114. Truckee, Cal. | 512 | 1805 | − .028 | − .162 | + .037 |
| 55. Mount Hamilton, Cal. | 1202 | 1282 | − .003 | + .003 | + .125 |
| 102. Cloudland, Tenn. | 1324 | 1890 | + .004 | − .042 | + .142 |
| 43. Pikes Peak, Colo. | 2035 | 4293 | + .021 | − .204 | + .216 |
| Mean with regard to sign | | | + .003 | − .118 | + .063 |
| Mean without regard to sign | | | .018 | .120 | .064 |

## *Mean anomalies.*

WITH REGARD TO SIGN.

| | Number of stations | New method | Bouguer | In free air |
|---|---|---|---|---|
| Coast stations | 18 | −0.004 | +0.021 | +0.021 |
| Stations near the coast | 25 | − .002 | − .004 | + .012 |
| Stations in the interior, not in mountainous regions | 39 | + .001 | − .030 | + .011 |
| Stations in mountainous regions, below the general level | 22 | .000 | − .132 | − .011 |
| Stations in mountainous regions, above the general level | 18 | + .003 | − .118 | + .063 |
| All stations (except the two Seattle stations) | 122 | .000 | − .048 | + .016 |

WITHOUT REGARD TO SIGN.

| | | | | |
|---|---|---|---|---|
| Coast stations | 18 | 0.018 | 0.027 | 0.027 |
| Stations near the coast | 25 | .022 | .027 | .021 |
| Stations in the interior, not in mountainous regions | 39 | .017 | .035 | .018 |
| Stations in mountainous regions, below the general level | 22 | .017 | .135 | .025 |
| Stations in mountainous regions, above the general level | 18 | .018 | .120 | .064 |
| All stations (except the two Seattle stations) | 122 | .018 | .063 | .028 |

In the table on page — it is shown that the mean new-method anomaly with regard to sign is 0.000 and without regard to sign is 0.018. The Seattle stations are omitted in the comparison of the anomalies of the several methods of reduction. In no particular would the conclusions arrived at be changed if they were retained.

In the above groups the means of the new-method anomalies with regard to sign are, respectively, −0.004, −0.002, +0.001, 0.000, and +0.003; and without regard to sign are 0.018, 0.022, 0.017, 0.017, and 0.018, respectively. In no case are the means much different from the means of the whole group of stations in the United States, and consequently it must be concluded that the effect of the topography and its compensation are adequately taken into account by the new method, and that the anomalies are due to local cause or causes which have no relation to the topography.

In considering the small anomalies it should be clearly borne in mind that the errors of observation and computation may frequently exceed 0.004 dyne, and in rare cases they may be as great as 0.010 dyne. (Page 87, Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, Special Publication No. 10.)

The mean Bouguer anomaly with regard to sign for 122 stations (see p. 12) is −0.048 dyne, while the means with regard to sign for the anomalies in the above five groups are, respectively, +0.021, −0.004, −0.030, −0.132, and −0.118. There is a great range in these values, and it is seen that the stations in mountainous regions have large negative values, while the mean for the coast stations is positive, but nearly zero. The mean Bouguer anomaly without regard to sign for all the stations is 0.063, while the mean Bouguer anomaly for the five groups is, respectively, 0.027, 0.027, 0.035, 0.135, and 0.120. The mean of the anomalies for the two groups of stations in mountainous regions is about twice the size of the mean of all. The anomalies at the stations in the other three groups are much smaller, on an average, and are more nearly comparable in size to the new-method anomalies. It is clear that the usual relations between the Bouguer anomalies and the topography exist in the United States.

The mean with regard to sign of the free-air anomalies for all of the stations is +0.016. (See p. 12.) The mean with regard to sign of the free-air anomalies at coast stations is +0.021, which is characteristic of this method of reduction. The mean with regard to sign of the anomalies at the stations near the open coast is +0.012, and the mean for the stations in the interior, but not in mountainous regions, is +0.011. It will be noticed that these three groups tend to have positive anomalies. This is what may be expected, for topography and compensation are neglected, and the resultant effect of the two is positive in most cases. (See table on p. 15.) Where the stations are in mountainous regions below the general level, the anomalies tend to be negative, which is the sign which might be expected, as the masses above the station have the effect of decreasing the force of gravity. The mean with regard to sign for this group is − 0.011 dyne. The mean free-air anomaly at the stations in the mountainous regions above the general level is +0.063 dyne, which is three times as great as the mean for any other group. A little reflection will make it clear that this large positive value results from ignoring the topography and compensation.

The means without regard to sign of the free-air anomalies are, respectively, 0.027, 0.021, 0.018, 0.025, and 0.064. The anomalies at coast stations and in mountainous regions are very much larger than the mean new-method anomaly. The stations back from the coast and the stations in the interior not in mountainous regions have anomalies which are, on an average, about equal to the mean new-method anomaly. The mean in the mountainous regions above the general level is about three and one-half times greater than the average new-method anomaly.

From the above comparisons it must be realized that the Bouguer and free-air anomalies have decided relations to the topography, consequently the anomalies from these two methods of reduction are of much less value than the new-method anomalies for the purpose of determining the distribution of materials in the earth's crust and for other geodetic purposes.

## GRAPHICAL COMPARISON OF THE THREE KINDS OF ANOMALIES.

A comparison of illustrations, Nos. 2, 3, and 4 at the end of this paper, will supplement the comparison of the three kinds of anomalies given on pages 12 to 15. One of the severest tests of a method of reduction is whether the positive and negative areas, as indicated by the signs of the anomalies, are nearly balanced in any extensive region under consideration. Illustrations Nos. 2, 3, and 4 show the areas of positive anomalies by the green shading and the negative areas by the yellow shading. Lines of equal anomalies, corresponding to contours on a topographic map, are drawn at intervals of 0.010 dyne or centimeter. The contours are in black, and no distinction is made between the positive and negative contours. In constructing the contours each station was connected by straight lines with the stations nearest it in each direction. Interpolations were made along each of the lines to fix the points through which the lines of equal anomaly pass. The contours are to be considered somewhat generalized. Illustration No. 2 shows the anomaly contours for the new method of reduction. The appearance of the map indicates that the areas of positive and negative anomalies are about equal in extent and that the grades as shown by the contours are not steep, except near Seattle. The positive areas form about 45 per cent of the whole area. There is no apparent connection between the contours on this illustration and the topography, except that the negative areas seem to predominate along the coasts. The negative anomalies at coast stations are, with few exceptions, very small and the geologic formation may be the cause of these. On pages 19 and 20 it is shown that the anomalies in the Cenozoic formation tend slightly to be negative. The formation on the coast is largely Cenozoic. The anomalies in the large negative area at the left side of the illustration may be partly due to the effusive and intrusive formations, which, sa shown on pages 19 and 20, tend to have negative anomalies. Although about 40 per cent more stations are considered here than in Special Publication No. 10, yet the contours on a similar illustration in that publication agree remarkably well with those on illustration No. 2 of this investigation.

Illustration No. 3 shows the lines of equal anomalies for the Bouguer reduction. The predominant characteristics of these contours are that nearly the whole area in the interior of the country is negative, the slopes are steep, and there is a decided relation between the topography and the size and sign of the anomalies. The low contours are in the areas with small elevations and the high contours are in the regions with great elevations. The sea-coast contours have a very decided tendency to be positive. The tendency of the Bouguer anomalies to be negative in the interior and positive on the coast is a characteristic of that method of reduction. Illustration No. 3 is in marked contrast to illustration No. 2, which shows the new-method anomaly contours. In the former only about 15 per cent of the total area is covered by positive contours.

Owing to the use of the Helmert formula for Vienna in the first investigation and the change in the adopted value of gravity at Washington from 980.111 to 980.112, each of the Bouguer and free-air anomalies in Special Publication No. 10 differs from the anomalies in this report by −0.017 dyne. In other words, in that publication the positive anomalies are less and the negative anomalies are greater by 0.017 dyne than the Bouguer and free-air anomalies considered here. The effect of the change from the formula of the Vienna system to that of the Potsdam system and the change of one thousandth of a dyne in the value of gravity for the base station is practically a change of datum for the Bouguer and free-air anomaly contour maps. The effect of this change of datum is scarcely noticeable on the Bouguer map.

The free-air anomaly contours are shown on illustration No. 4. The positive area greatly predominates, only 25 per cent of the total area being negative. This is in great contrast to the Bouguer contours on illustration No. 3. A comparison of illustrations Nos. 2 and 4 shows that each negative area of the free-air anomaly map comes within a negative area of the new-method anomaly map. The difference between the two maps is principally in the different sizes of the negative areas.

In several cases there were two stations close together with great differences in elevation. In each case the anomaly of the station with the elevation nearest the general elevation of the surrounding country was used for controlling the contours.

An analysis of the three methods indicates clearly the cause of the principal characteristics of the three anomaly contour maps. By the Bouguer method the effect of the compensation is ignored and the computed gravity at a station in the interior is too great and on and near the coast the computed gravity is too small. Hence the anomaly contours will be negative in the interior and will tend to be positive at the coast. In the free-air reduction the resultant of the effect of the topography and its compensation is ignored, and the result is that in general the computed gravity is too small, and the anomalies have a marked tendency to be positive. The new method takes into account both the topography and the compensation and consequently the anomalies should not show any decided tendency to be of one sign and there should be no relation between the size and sign of the anomalies and the topography. An inspection of the new-method anomaly contour map shows that these conclusions are borne out by the facts.

### RELATION BETWEEN NEW-METHOD ANOMALIES AND AREAS OF EROSION AND DEPOSITION.

It is reasonably certain that the erosion and deposition of material has an effect on the intensity of gravity, but no clear relation can be discovered between the new-method gravity anomalies and areas of erosion and deposition. At the mouths of rivers carrying great quantities of materials one should expect gravity to be in excess. But in the United States the anomalies at stations near the mouths of large rivers have both signs. The fact that there is no definite relation between the new-method anomalies and areas of erosion and deposition indicates that the isostatic adjustment takes place soon after (geologically) the changes in the topography.

### RELATION BETWEEN THE NEW-METHOD ANOMALIES AND THE GEOLOGIC FORMATIONS.

The following tables show the geologic formation in which each of the gravity stations is located. The 124 stations used in this investigation were platted on the geologic map of North America which bears the following title: "Geologic Map of North America, compiled by the United States Geological Survey, in cooperation with the Geological Survey of Canada and Instituto Geologico De Mexico, under the supervision of Bailey Willis and George W. Stose, Scale 1:5,000,000, 1911." The decision as to the surface geologic formation on which the stations are located was based entirely on this map. It is probable that the classification would be slightly different if some other source of information were used.[1] The writer believes, however, that only minor changes would be made in the tables given below and the conclusions drawn from them would not be materially changed.

In the tables are given the stations and their new-method anomalies for each of the following formations: (1) Archeozoic and Proterozoic, (2) Paleozoic, (3) Mesozoic, (4) Cenozoic, (5) Effusive, (6) Intrusive, (7) Unclassified.

*Stations and new-method anomalies for specified formations.*

ARCHEOZOIC AND PROTEROZOIC FORMATIONS.

| Station number | New-method anomaly in dynes | Station number | New-method anomaly in dynes | Station number | New-method anomaly in dynes | Station number | New-method anomaly in dynes |
|---|---|---|---|---|---|---|---|
| 16 | +.015 | 45 | +.020 | 58 | +.023 | 102 | +.004 |
| 24 | +.022 | 57 | +.038 | 75 | +.052 | 107 | +.024 |
| 43 | +.021 | | | | | | |

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[1] In the publication The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity the decision as to the geologic formation on which the 89 stations there considered was based upon the geological map of North America bearing the following title: "Carte Géologique de L'Amérique du Nord, Dressée d'apres les sources officelles des Etats Unis, du Canada, de la République du Mexique, de la Commission du Chemin de Fer Intercontinental, etc., Henry Gannett, Géographe, et Bailey Willis, Géologue, Echelle, 1:5,000,000, 1906."

*Stations and new-method anomalies for specified formations*—Cotinued.

PALEOZOIC FORMATION.

| Station number | New-method anomaly in dynes | Station number | New-method anomaly in dynes | Station number | New-method anomaly in dynes | Station number | New-method anomaly in dynes |
|---|---|---|---|---|---|---|---|
| 12 | −.027 | 35 | −.009 | 74 | +.059 | 105 | −.021 |
| 14 | +.026 | 36 | −.007 | 78 | +.002 | 106 | −.013 |
| 20 | +.010 | 37 | −.005 | 85 | +.001 | 119 | +.015 |
| 29 | +.005 | 38 | −.005 | 88 | −.010 | 120 | −.008 |
| 30 | +.005 | 39 | −.016 | 89 | −.020 | 121 | +.002 |
| 32 | −.023 | 59 | +.019 | 96 | −.052 | 122 | +.011 |
| 33 | −.003 | 61 | −.029 | 101 | +.040 | 123 | −.043 |
| 34 | −.019 | 72 | +.032 | 104 | −.024 | 124 | −.033 |

MESOZOIC FORMATION.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10 | −.008 | 42 | −.007 | 60 | +.001 | 77 | +.029 |
| 11 | −.010 | 46 | +.024 | 62 | +.031 | 91 | +.036 |
| 23 | −.011 | 47 | −.021 | 70 | −.013 | 94 | −.017 |
| 25 | −.019 | 54 | −.023 | 71 | +.003 | 108 | −.006 |
| 40 | +.014 | 55 | −.003 | 73 | +.005 | 118 | +.014 |

CENOZOIC FORMATION.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | +.008 | 17 | −.021 | 76 | +.002 | 97 | −.011 |
| 2 | +.018 | 18 | −.021 | 79 | +.008 | 99 | −.016 |
| 3 | +.010 | 44 | −.016 | 80 | −.013 | 100 | −.017 |
| 4 | 000 | 53 | [1]−.093 | 82 | +.013 | 109 | [2]+.032 |
| 5 | −.013 | 56 | | 83 | −.006 | 112 | +.033 |
| 6 | +.016 | 63 | +.007 | 90 | −.048 | 115 | −.009 |
| 7 | −.009 | 64 | −.050 | 92 | +.010 | 117 | [3]+.036 |
| 8 | +.027 | 65 | +.009 | 93 | −.044 | | |
| 9 | −.020 | 66 | −.050 | 95 | +.001 | | |

EFFUSIVE FORMATION.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 50 | −.002 | 52 | −.001 | 98 | +.021 | 113 | −.027 |
| 51 | +.021 | 81 | −.010 | 110 | −.015 | 114 | −.028 |

INTRUSIVE FORMATION.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 28 | −.020 | 86 | +.006 | 103 | −.029 | 111 | −.028 |
| 31 | −.008 | | | | | | |

UNCLASSIFIED.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 13 | +.030 | 22 | +.039 | 48 | +.004 | 69 | −.010 |
| 15 | −.023 | 26 | +.024 | 49 | +.010 | 84 | +.037 |
| 19 | −.013 | 27 | +.022 | 67 | −.013 | 87 | +.021 |
| 21 | +.037 | 41 | −.012 | 68 | +.001 | 116 | −.021 |

[1] Only one anomaly is used for the two Seattle stations.

[2] This station is only 14 miles from a pre-Cambrian formation.

[3] This station is only 6 miles from a pre-Cambrian formation.

The unclassified stations are those which plot on the geologic map near the dividing line between two formations, or in a locality where there are several formations within a few miles of the station.

The table shown below gives the means of the new-method anomalies with and without regard to sign and the number of stations in each of the several groups.

*Summary.*

| Geologic formation | Number of stations | | | Mean anomaly | |
|---|---|---|---|---|---|
| | All | With plus anomalies | With minus anomalies | With regard to sign | Without regard to sign |
| Archeozoic and Proterozoic | 9 | 9 | 0 | +0.024 | 0.024 |
| Paleozoic | 32 | 13 | 19 | − .004 | .019 |
| Mesozoic | 20 | 9 | 11 | + .001 | .015 |
| Cenozoic | 33 | 15 | 17 | − .007 | .021 |
| Effusive | 8 | 2 | 6 | − .005 | .016 |
| Intrusive | 5 | 1 | 4 | − .016 | .018 |
| Unclassified | 16 | 10 | 6 | + .008 | .020 |
| All stations | 123 | 59 | 63 | − .001 | .019 |

One station in the Cenozoic formation has a zero anomaly. Only one anomaly was used for the two Seattle stations. Those stations are very near together, and the same very large anomaly, −0.093 dyne, is found at each. The introduction of the second anomaly would only have enlarged the means given in the table.

The data shown in the above table are in substantial agreement with the table shown on page 114 of the Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, Special Publication No. 10.

The mean of all the 123 anomalies with regard to sign is −0.001 dyne and the mean without regard to sign is 0.019 dyne. These means each differ 0.001 from those given in the table on page —, owing to the introduction of the anomaly of −0.093 at one of the Seattle stations. It is evident from the above table that gravity is in excess and the topography under compensated at the stations in the Archeozoic and Proterozoic formations, for all of the nine anomalies are plus and the mean with regard to sign is +0.024. This is necessarily the average size of the anomaly without regard to sign, and it is considerably larger than the mean of the anomalies at all of the stations. There was one station, No. 15, at Atlanta, Ga., with a negative anomaly, which is on a narrow strip of old rock but this narrow strip runs through an extensive area of intrusive rock. As this station was within 2 miles of the intrusive rocks it was placed in the unclassified group.

The most recent formation, the Cenozoic, has 33 stations, the anomalies of which are nearly equally divided as to sign, and the mean with regard to sign is −0.007 dyne. This would indicate that the topography in this formation is overcompensated and gravity is in defect. However, the very large anomaly at the Seattle station has a great influence on the size of the mean of this group and it will be well to consider the condition of the anomalies with this station omitted. If it is rejected, there will remain 32 stations in the Cenozoic formation, 15 with plus and 16 with minus anomalies and one with a zero anomaly. The mean with regard to sign will then be −0.004, which is very close to normal, and the mean without regard to sign will be 0.018, which is the average size of all the anomalies in the United States after rejecting the Seattle stations.

The Paleozoic and Mesozoic formations which are of intermediate ages have 32 and 20 stations respectively In each the minus anomalies are slightly more numerous than the plus anomalies. The Paleozoic anomalies have a mean of −0.004 with regard to sign and 0.019 without regard to sign. The Mesozoic anomalies have a mean with regard to sign of +0.001 and without regard to sign the mean is only 0.015.

There are 8 stations in the Effusive formation and 6 have minus anomalies. The mean with regard to sign is −0.005, which indicates that gravity is somewhat in defect and the topography overcompensated. The largest anomaly in this formation is only 0.028. There are only 5 stations in the Intrusive formation and 4 of them have negative anomalies. The one anomaly with the positive sign is only +0.006. The mean of the five anomalies with regard to sign is −0.016, which shows that the gravity is very much in defect and the topography largely overcompensated. The largest anomaly in this formation is 0.029. If the Intrusive and Effusive anomalies were combined into one group then the mean with and without regard to sign would be −0.009 and 0.017 respectively.

Of the 14 plus anomalies of 0.030 or greater, 2 are in the Archeozoic and Proterozoic group, 3 in the Paleozoic, 2 in the Mesozoic, 3 in the Cenozoic and 4 in the Unclassified. There are 9 negative anomalies of 0.030 or larger. Of these 3 are in the Paleozoic and 6 in the Cenozoic. There is no anomaly as great as ±0.030 in the Effusive or Intrusive formations.

In general the rocks of the oldest formations have greater densities than 2.67, the adopted mean value for the surface density of the earth, and this fact may lead one to conclude that the gravity should be greater on these formations. But it will appear on reflection that these can not be merely surface phenomena.

Let it be assumed that the pressure at the depth of 113.7 kilometers under a station of the oldest formations is normal (that is, the crust is in a state of perfect isostasy) and let it be assumed that the average anomaly with regard to sign of +0.024 is caused by an erroneous assumption regarding the surface density. Then if the formation considered extends 19 kilometers in every direction from the station and to a depth of 1000 feet, an increase in density of 2.06 would be necessary to cause an anomaly of +0.024. With the same radius but a depth of 10 000 feet the necessary increase of density would be 0.20.

The maximum anomaly in the oldest formation is +0.052 and this could be caused by an increase in density of 0.43 in a disk of material about the station with a radius of 19 kilometers and a depth of 10 000 feet.

With the depth of 10 000 feet and a radius of 19 kilometers in the geologic formation at a station, the average anomaly of −0.016 in the Intrusive group could be caused by a change in density of −0.13.

To cause the maximum negative anomaly of −0.093, at Seattle, would require a decrease of density of 0.82 in the material of a disk 10 000 feet thick and a radius of 19 kilometers directly under the station.

A more reliable geologic map and 35 more gravity stations were used in this investigation than in the first one, but the data in the above table are in general in close agreement with those shown in the table on page 114 of the report on the first investigation. They differ in regard to the Intrusive and Effusive formations the anomalies of which in the first investigation have a mean with regard to sign that is about normal, while in this investigation the anomalies have a strong tendency to be negative. Also the anomalies of the Cenozoic formation in the present investigation have a mean with regard to sign of only −0.007, while in the first investigation it was −0.011 dyne. The second investigation shows that the mean with regard to sign at stations in the oldest formations is somewhat greater than in the first investigation. The data from the two investigations for the Paleozoic and Mesozoic formations agree very closely.

From the considerations stated above it seems probable that the excesses and deficiencies of mass which cause the largest of the anomalies can not be surface phenomena alone and that such excesses and defects must extend through depths at least as great as 15 000 feet. There is no conclusive evidence from gravity observations to indicate whether the anomalies of the average size are caused by difference between the actual and the assumed density of the earth's surface material near the station or whether such anomalies are caused by an actual departure from a state of complete isostasy.

## NEW-METHOD ANOMALIES IN AGREEMENT WITH DEFLECTIONS-OF-THE-VERTICAL RESIDUALS.

Illustration No. 5. shows the residuals of solution H of the Supplemental Investigation in 1909 of the Figure of the Earth and Isostasy, and the gravity stations with their new-method anomalies. The deflections indicated that there was an excess of mass in some areas and a defect of mass in others. These areas are shown by red lines on this illustration. In only one or two cases was the gravity known before the outlines of the areas were drawn. Since the publication of the Supplemental Investigation in 1909 of the Figure of the Earth and Isostasy, in which this illustration first appeared, at least one gravity station was established in or very near each of the areas inclosed by red lines except the areas near Chester, Ill., and near the Santa Barbara Channel, Cal. In no case did the sign, as indicated by the deflection residuals, differ from the sign of the new-method anomalies of the gravity stations. Wherever the gravity stations are near the astronomic stations there is no important conflict between the evidence furnished by the deflections and the gravity stations as to the location of areas of excessive and defective density. It is possible that an investigation based upon a combination of deflection and gravity stations may furnish means to determine approximately the location with respect to depth of the excesses and deficiencies of mass.

## REGIONAL VERSUS LOCAL DISTRIBUTION OF COMPENSATION.

On pages 98 to 102 of the "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity" there was a discussion under the above heading. The anomalies were computed with regional distribution of the compensation within the outer limits of zones K, M, and O (radii of 18.8, 58.8, and 166.7 kilometers, respectively). The evidence for the first investigation was from only 44 stations in the United States and 4 foreign stations. These data are now supplemented by similar data for all the remaining stations in the United States. The average anomaly with regard to sign by the new method with local compensation, and the average anomaly by each of the three new-method reductions with regional distribution of the compensation are repsectively −0.002, −0.001, −0.001, and −0.002 dyne. The means without regard to sign for the different distributions of the compensation are respectively, 0.020, 0.019, 0.019 and 0.020 dyne. These mean anomalies give only negative evidence.

There are 22 stations in the United States in mountainous regions and below the general level and the means, with regard to sign, of the anomalies by the four methods of distribution are 0.000, +0.001, +0.003, and +0.005 dyne, while the means without regard to sign are respectively 0.017, 0.017, 0.018, and 0.019 dyne. For the 18 stations in the United States in mountainous regions and above the general level the means, with regard to sign, of the anomalies by the several methods of distribution of the compensation are +0.003, +0.003, 0.000, and −0.010 dyne. The means without regard to sign, are respectively 0.018, 0.018, 0.017, and 0.020 dyne.

The mean, with regard to sign, of the anomalies for the stations at each of the two mountain groups, indicates that the theory of regional distribution of compensation to the outer limit of zone O, 166.7 kilometers, is far from the truth. So far as may be judged from the other average anomalies no one method seems to have any decided advantage. (See pp. 98–102 of Special Publication No. 10.)

## PERCENTAGE OF COMPLETENESS OF COMPENSATION.

On page 111 of Special Publication No. 10 it was shown that the gravity anomaly may be interpreted in terms of excess or deficiency of masses of known extent. As a mean working hypothesis it was assumed that ordinarily 0.0030 dyne of anomaly is due to an excess or deficiency of mass equivalent to a stratum 100 feet thick. This working hypothesis is equivalent either to the assumption that excess (or deficiency) of mass is uniformly distributed to a depth of 113.7 kilometers and extends to a distance of 166.7 kilometers and less than 1190 kilometers from the station, or to the assumption that it extends to a distance of 166.7 kilometers from the station and is distributed to an effective mean depth of more than 15 000 feet and less than 113.7 kilometers, or the working hypothesis may be considered to be a combination of the two assumptions.

From the evidence given by deflections of the vertical the conclusion has been drawn that in the United States the average departure from complete compensation corresponds to excesses or deficiencies of mass represented by a stratum only 250 feet thick on an average.[1] The gravity determinations indicate this average to be 630 feet instead of 250 feet. In neither case is the average value determined or defined with a high grade of accuracy. The difference between the two determinations of the average value is therefore of little importance. The determination given by the gravity observations is probably the more reliable of the two. Each determination is significant mainly as showing that the isostatic compensation is nearly perfect.

The average elevation in the United States above mean sea level is about 2,500 feet. Therefore, from gravity observations alone the compensation may be considered to be about 75 per cent complete on an average for stations in the United States.

## DEPTH OF COMPENSATION.

No tests of the depth of compensation from the anomalies have been made except for 10 stations, for which data are given on page 105 of Special Publication No. 10. It is hoped to make a test in the near future of the depth of compensation with the new-method gravity anomalies at all stations in the United States.

## ALASKA GRAVITY STATIONS.

There are shown in the table given below the principal facts for 10 stations in Alaska[2] established by the Coast and Geodetic Survey. Only the stations at St. Paul Island in 1891, at St. Michael in 1898, and at Fort Egbert in 1905 can be considered primary in character. The other stations were established incidentally to other field work, and the determination of the chronometer corrections was weak. At all of the stations the half-second pendulums were used. It is difficult to obtain a definite idea as to the accuracy of the derived value of the intensity of gravity at the stations other than St. Paul, St. Michael, and Fort Egbert. The writer believes, however, that the value of the intensity of gravity at each of the secondary stations may be uncertain by as much as 0.020 dynes.

| Name of station | $\phi$ | | $\lambda$ | | $H$ | $\gamma_0$ | Correction for elevation | Correction for topography and compensation | Computed gravity at station ($g_c$) | Observed gravity at station ($g$) | $(g-g_c)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ° | ′ | ° | ′ | *Meters* | | | | | | |
| Fort Egbert, Eagle City | 64 | 47.4 | 141 | 12.4 | 269 | 982.271 | −0.083 | −0.042 | 982.146 | 982.183 | +0.037 |
| Juneau | 58 | 17.5 | 134 | 24 | 5 | 981.778 | − .002 | − .075 | 981.701 | 981.744 | + .043 |
| Yakutat Bay | 59 | 33.8 | 139 | 47.3 | 4 | 981.880 | − .001 | − .018 | 981.861 | 981.835 | − .026 |
| Pyramid Harbor | 59 | 11.8 | 135 | 26.8 | 5 | 981.850 | − .002 | − .086 | 981.762 | 981.822 | + .060 |
| Sitka | 57 | 02.9 | 135 | 20.4 | 9 | 981.676 | − .003 | + .007 | 981.680 | 981.694 | + .014 |
| Wrangell | 56 | 28.3 | 132 | 23.2 | 7 | 981.628 | − .002 | − .047 | 981.579 | 981.603 | + .024 |
| Burroughs Bay | 56 | 02.2 | 131 | 06.1 | 0 | 981.591 | .000 | − .067 | 981.524 | 981.507 | − .017 |
| St. Paul Island | 57 | 07.3 | 170 | 16.6 | 10 | 981.682 | − .003 | + .041 | 981.720 | 981.726 | + .006 |
| St. Michael | 63 | 28.5 | 162 | 02.4 | 1 | 982.178 | .000 | − .004 | 982.174 | 982.192 | + .018 |
| Port Simpson, British Columbia | 54 | 33.6 | 130 | 25.5 | 6 | 981.466 | − .002 | − .029 | 981.435 | 981.464 | + .029 |

In the following table there are given the anomalies at the Alaska stations for the three methods of reduction. The anomalies for the two older methods were copied from Verhandlungen, Sechzehnten Allgemeinen Conferenz, Internationalen Erdmessung, III Teil, Berlin, 1911, except in the case of Fort Egbert. After this place was connected with the seacoast by precise leveling the elevation used for the gravity station was changed from 174 meters to 269 meters. The change in elevation will account for the difference in the anomalies at Fort Egbert from those given in the above publication.

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[1] The Figure of the Earth and Isostasy, etc., pp. 164–166, and Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy, p. 59.

[2] One of these stations at Port Simpson is really in Canadian territory, near the extreme portion of southeastern Alaska.

| Name of station | Anomaly | | |
|---|---|---|---|
| | New method $g-(g_c+0.008)$ | Bouguer $(g''_o-\gamma_o)$ | In free air $(g_o-\gamma_o)$ |
| Fort Egbert, Eagle City | +0.029 | −0.031 | −0.005 |
| Juneau | + .035 | − .033 | − .032 |
| Yakutat Bay | − .034 | − .044 | − .044 |
| Pyramid Harbor | + .052 | − .027 | − .026 |
| Sitka | + .006 | + .020 | + .021 |
| Wrangell | + .016 | − .024 | − .023 |
| Burroughs Bay | − .025 | − .084 | − .084 |
| St. Paul Island | − .002 | + .046 | + .047 |
| St. Michael | + .010 | + .014 | + .014 |
| Port Simpson, British Columbia | + .021 | − .001 | .000 |

Owing to the small number of stations in Alaska and the fact that 7 of the 10 stations are not primary in character, it will not serve any useful purpose to discuss them as a group. The data for these stations are inserted in this paper for use in getting a value for the flattening of the earth. (See p. 23.) It is hoped that a number of primary gravity stations may be established in Alaska in the not distant future.

## FLATTENING OF THE EARTH.

In the writer's opinion the severest test to which the new method can be subjected is a determination of the flattening of the earth from the stations in the United States, which are few in number and limited in range of latitude as compared with those used by Helmert in deducing his flattening, 1/298.3.

The stations in the United States were arranged in groups according to latitude. (In these tests the two Seattle stations were rejected.) The zones selected for the groups were four degrees wide, with middle latitudes of 27°, 31°, 35°, 39°, 43°, and 47°, respectively. The Helmert formula of 1901, $\gamma_o=978.030(1+0.005302\sin^2\phi-0.000007\sin^2 2\phi)$, was used as a basis of the computations, and the anomaly at each station was given unit weight, except that where there was a group of two or more stations located close together the mean anomaly for the group was used. This mean anomaly for a group was also given unit weight. The mean anomalies for the stations in the several zones selected were assumed to have been due entirely to erroneous values of the coefficients in the Helmert formula.

The coefficient 0.000007 was assumed to be correct.

The general form of observation equation is:

$$0=(\gamma_o-g_o)+(1+0.005302\ \sin^2\phi-0.000007\ \sin^2 2\phi)X_1+978.030\ \sin^2\phi X_2.$$

$\gamma_o$ is the computed value of gravity as given by Helmert's formula. $g_o$ is the corresponding observed value reduced to sea level and corrected for topography and isostatic compensation. $\gamma_o-g_o$ is, therefore, the new-method anomaly with reversed sign. $X_1$ is the correction to 978.030, and $X_2$ is the correction to 0.005302.

In the following table there are given for each zone the number of anomalies and the average new-method anomaly. As stated above, the mean anomaly was taken where two or more stations were close together.

| Number of anomalies | Middle latitude of zone | Anomaly, new method | Number of anomalies | Middle latitude of zone | Anomaly, new method |
|---|---|---|---|---|---|
| 5 | 27° | +0.017 | 29 | 39° | +0.004 |
| 15 | 31° | +0.002 | 28 | 43° | +0.012 |
| 21 | 35° | +0.003 | 16 | 47° | +0.011 |

The observation equations are:

$$\begin{aligned}
0&=-0.017+1.0011X_1+201.6X_2\\
0&=-0.002+1.0014X_1+259.4X_2\\
0&=-0.003+1.0017X_1+321.8X_2\\
0&=-0.004+1.0021X_1+387.5X_2\\
0&=-0.012+1.0025X_1+455.0X_2\\
0&=-0.011+1.0028X_1+523.1X_2
\end{aligned}$$

The normal equations are:

$$\begin{aligned}
0&=-0.04910+6.0232X_1+2152.95X_2\\
0&=-17.6755+2152.95X_1+842301.0X_2.
\end{aligned}$$

The solution gives:

$$\begin{aligned}
X_1&=+0.00753\\
X_2&=+0.00000174.
\end{aligned}$$

The resulting formula for the theoretical value of gravity at sea level is:

$$\gamma_0=\underset{\pm 6}{978.038}(1+\underset{\pm 17}{0.005304}\sin^2\phi-0.000007\sin^2 2\phi).$$

The derived reciprocal of the flattening is 298.4 ± 1.5, which agrees almost exactly with the Helmert value, 298.3 ± 0.7, as derived from a great many gravity stations having a great range in latitude. The probable errors of the terms in the new formula are large and are probably due to the very large mean positive anomaly for latitude 27°. In the table above it will be seen that there are only five stations in this group.

On page 10 a correction of +0.008 was applied to the first term of Helmert's formula. This was the mean anomaly with regard to sign for 122 gravity stations in the United States (Seattle stations omitted). The above formula derived from the stations in the United States shows that the application of this correction was justified. The writer does not believe that it would be advisable to change the second term of Helmert's formula as the new value for the second term has not the precision of the new value for the first term.

In order to test the reliability of this value of the reciprocal of the flattening from all stations in the United States the stations were divided into two groups, those east of the ninety-seventh meridian of longitude and those west of that meridian.

With 62 anomalies east of longitude 97° the theoretical formula is:

$$\gamma_0=\underset{\pm 8}{978.040}(1+\underset{\pm 20}{0.005297}\sin^2\phi-0.000007\sin^2 2\phi).$$

and the resulting reciprocal of the flattening is 297.8 ± 1.8.

For the 52 anomalies to the west of longitude 97° the theoretical formula is:

$$\gamma_0=\underset{\pm 8}{978.032}(1+\underset{\pm 21}{0.005319}\sin^2\phi-0.000007\sin^2 2\phi).$$

and the derived reciprocal of the flattening is 299.6 ± 1.9.

These values of the reciprocal of the flattening are in such close agreement with the best values derived from great numbers of gravity observations and deflections of the vertical that it is believed that the results prove that the new method of reduction is very close to the truth and that the area of the United States is in a state of nearly perfect isostatic equilibrium.

A further test was made by combining the anomalies at the 10 Alaska stations with those in the United States. The resulting theoretical formula is:

$$\gamma_0=\underset{\pm 4}{978.030}(1+\underset{\pm 8}{0.005326}\sin^2\phi-0.000007\sin^2 2\phi).$$

and the derived reciprocal of the flattening is 300.4 ± 0.7.

Owing to the secondary character of 7 of the 10 Alaska gravity stations the mean anomalies for the two 5-degree zones used, with middle latitudes 56° 30′ and 61° 30′, may be largely in error from the observations alone. Also the topographic maps used in reducing the Alaska stations were not very accurate and the errors from this source may be some thousandths of a dyne. However, the reciprocal of the flattening from the combination of the United States and Alaska stations is close to those derived from the stations in the United States alone.

The close agreement of the above four values of the reciprocal of the flattening of the earth from the new method of reduction can not be fully appreciated until they are compared with the values derived from the anomalies by the older methods of reduction.

By following the same method of computation as that used for the new method and using 122 stations in the United States (omitting the Seattle stations) the theoretical formula resulting from the free-air method is:

$$\gamma_0 = \underset{\pm 7}{978.072}(1 + \underset{\pm 19}{0.005232} \sin^2\phi - 0.000007 \sin^2 2\phi).$$

The deduced reciprocal of the flattening is 292.1 ± 1.7.

The reciprocal of the flattening for the stations in the eastern half of the United States from this method is 292.4 ± 3.0, for the western half of the United States it is 294.3 ± 2.8, and for the combination of the Alaska stations and those in the United States the reciprocal of the flattening is 291.2 ± 0.7.

Similarly the theoretical formula resulting from the Bouguer method of reduction, using the 122 stations in the United States, is:

$$\gamma_0 = \underset{\pm 31}{978.070}(1 + \underset{\pm 82}{0.005092} \sin^2\phi - 0.000007 \sin^2 2\phi)$$

and the derived reciprocal of the flattening is 280.7 ± 7.2.

The reciprocal of the flattening for the stations in the eastern half of the United States from the Bouguer method is 284.9 ± 3.3, for the western half of the United States it is 279.1 ± 12.5, and for the combination of the stations in Alaska and the United States it is 296.1 ± 4.1.

The following table gives the reciprocal of the flattening for each of the three methods of reduction for each of the four groups of stations considered:

*Summary of values of reciprocal of the flattening.*

| | New method | Free air | Bouguer |
|---|---|---|---|
| All stations in the United States | 298. 4±1. 5 | 292. 1±1. 7 | 280. 7± 7. 2 |
| Stations in eastern half of United States | 297. 8±1. 8 | 292. 4±3. 0 | 284. 9± 3. 3 |
| Stations in western half of United States | 299. 6±1. 9 | 294. 3±2. 8 | 279. 1±12. 5 |
| Combination of stations in Alaska and the United States | 300. 4±0. 7 | 291. 2±0. 7 | 296. 1± 4. 1 |

It is seen that the values of the flattening derived from the older methods of reductions are far from the truth (except the last Bouguer value shown), and it is apparent that no reliable values can be obtained from those methods with limited numbers of stations in a small range of latitude. In contrast the values from a small number of stations reduced by the new method and with a small range of latitude are very near the truth.

It is the writer's belief that if all the available gravity stations of the world were reduced by the new method of reduction a theoretical formula for gravity at sea level and a value of the flattening of the earth could be obtained which would have very great precision, and be extremely close to the truth.

## SUMMARY.

The second or supplementary investigation of the Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, of which this paper is a report, gives results which agree in every important particular with the results of the first investigation which are published in the United States Coast and Geodetic Survey publication entitled "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, Special Publication No. 10," by J. F. Hayford and William Bowie.

In the first investigation the Helmert formula in the Vienna system was used for computing the theoretical value of gravity at sea level. The stations in the United States are in the Potsdam system, and thus an error was made in the theoretical gravity at sea level for each station. This did not affect the new-method anomalies, for, before computing them, a correction was applied to the first term of Helmert's formula. This correction was equal to the mean with regard to sign of the difference between the observed and computed values of gravity at each station in the United States. The result of the use of the wrong formula on the Bouguer and free-air anomalies was to apply −0.016 dyne to each. In the supplementary investigation the Helmert formula in the Potsdam system has been used and the anomalies by each method of reduction are not subject to the above errors. The effect on the anomalies by the older methods of reduction may be clearly seen by comparing the means with regard to sign for the several groups of stations arranged according to the topography shown on pages 14 to 15 of this paper and on pages 77 to 78 of the Effect of Topography and Isostatic Compensation upon the Intensity of Gravity. The effects will be seen graphically by a comparison of illustrations Nos. 3 and 4 of this paper with illustrations Nos. 17 and 18 of the other publication.

The more recent geological map used in this investigation gave a different geologic formation around some of the stations from that stated in the first investigation. The mean anomalies with regard to sign are nearly zero for the stations in the Mesozoic and Paleozoic formations. If the two Seattle stations are not considered then the other 32 stations in the Cenozoic formation will have a mean anomaly with regard to sign of −0.004, which is very nearly normal. The anomalies at each of the 9 stations in the oldest formations are positive with a mean of +0.024. This indicates an excess of mass in the crust of the earth under these formations (p. 20). Of the anomalies at stations in Effusive and Intrusive formations 10 are negative and only 3 positive. The mean with regard to sign for these anomalies is − 0.009 which indicates that there is in general a defect of mass in the earth's crust under these formations (p. 20).

It is probable that the causes of the anomalies are not merely surface phenomena. The average anomaly can not be accounted for by any reasonable assumption as to regional distribution of compensation (p. 22) nor by a horizontal displacement of the compensation (p. 121 of the Effect of Topography and Isostatic Compensation upon the Intensity of Gravity.) Neither is it possible to account for the anomalies by any reasonable difference in the depth of compensation (p. 105 Special Publication No. 10). They are probably due in part to errors of observation and computation, to erroneous values in the assumed density of the materials of the upper portion of the earth's crust near the station, and variations in the manner of distribution of the compensation with respect to depth (p. 22). The writer believes, however, that the principal cause of the larger anomalies is an actual departure from the state of perfect isostasy in the vicinity of the stations.

It is the writer's belief that the principal causes of the larger new-method anomalies are located within restricted areas surrounding the stations. This is clearly indicated graphically on illustration No. 2, which shows the stations and their new-method anomalies and the gravity contours. Particular notice should be given the change in anomaly from −0.020 at station 9 to +0.027 at station 8 in a distance of only 280 kilometers; the change from −0.093 at stations 53 and 56 to +0.033 at station 112, in a distance of only 90 kilometers; the change from −0.021 at station 47 to +0.024 at station 46, a distance of only 140 kilometers; and the change from +0.037 at station 21 to −0.011 at station 23, in a distance of only 62 kilometers. There are numerous other pairs of stations which show large changes in the anomalies in comparatively short distances. This change in the anomalies at stations near each other is not confined to any particular type of topography.

Four groups of gravity stations were used for determining the flattening of the earth. The new method of reduction gave values which ranged from 1/297.8 to 1/300.4 (p. 26) and the value obtained by using all of the stations in the United States exclusive of Alaska is 1/298.4, which is almost identical with the Helmert value 1/298.3 obtained from a great many gravity stations extending over a great range in latitude. It is also in fair agreement with the Hayford values 1/297.8 and 1/297.0 from the two investigations of the Figure of the Earth and Isostasy from Measurements in the United States.

The four values of the flattening obtained from the free-air reduction ranged from 1/292.1 to 1/294.3. All of the stations in the United States alone gave the value 1/292.1. This is very far from the generally accepted best values for the flattening.

The four values of the flattening from the Bouguer reduction range from 1/279.1 to 1/296.1. The value derived from all the stations in the United States (excluding Alaska) is 1/280.7, which is very far from the truth.

The investigations of the effect of topography and isostatic compensation upon the intensity of gravity made by the United States Coast and Geodetic Survey supplement the investigations of the figure of the earth and isostasy from deflections of the vertical, and in no important particular do the results of the two classes of investigations conflict. (See p. 21).

The results of these four investigations show clearly that the portion of the earth's crust covered by the United States proper is, on an average, in practically a state of complete isostasy. There are local deviations from that perfect state which amount, on an average, to about 25 per cent (p. 23). The areas having an excess of mass are about equal in extent to those having a deficiency of mass (p. 17). The large new-method anomalies are distributed over the whole country and do not tend to be systematic for any extensive area (illustration No. 2). The new-method anomalies appear to follow approximately the law of distribution of accidental error both as to size and distribution (table on p. 12 and illustration No. 2.)

There is no apparent relation in sign or size between the new-method anomalies and the topography. These anomalies are practically normal near stations on the coast; in the interior, not in mountainous regions; and in mountainous regions. There are very marked relations between the topography and the anomalies by the Bouguer and free-air methods. (See pp. 14 to 15).

The new method of reduction is very much nearer the truth than either of the two older methods of gravity reductions. The writer believes a flattening of the earth obtained from all the gravity stations of the world reduced by the new method would have a precision many times greater than any value of the flattening now available.